DECISION SUPPORT SYSTEM FOR RURAL WATER SUPPLY IN THE NILGIRIS DISTRICT OF SOUTH INDIA

BY

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ABSTRACT

A considerable amount of knowledge exists for planning, designing, and implementing rural water supply schemes in developing countries around the world. Generic decision support systems (DSS) and techniques are used to tackle the daunting task of providing water in areas that have poor water resources and limited financial capacity. However, there is a lack of site-specific DSS that utilise local hydrological and socio-economic data for assessing regionally-based rural water supply schemes. In the Nilgiris District of South India, an organizational structure exists for improving local water resources through watershed management projects, but many of the tools used to make informed decisions are ineffective, leading to poorly designed systems.

Developing a DSS that uses models applicable to the local conditions, minimizes the need for gathering complex data, and incorporates non-technical factors into the computer algorithms, would greatly improve the process for selecting rural water supply sources in the Nilgiris District. Organising the selection process into a user-friendly computer program would not only benefit the social and economic status of the villages, but also improve the environmental condition of the watershed area.

As a result of the need for an improved organizational structure for rural water supply, a prototype DSS called NRWS (Nilgiris Rural Water Supply) was developed in this research. NRWS aids in the process of identifying key issues in selecting sustainable water sources, and systematically guides the user through various methodologies to quantify the potential water sources. The shell of NRWS is developed through Microsoft® Excel using the Visual Basic for Applications programming language. A user-friendly interface directs the user through the program functions by a network of links and forms. The DSS is divided into six modules that represent different criteria used to evaluate potential water sources: water source yield, capital costs, cost and ease of operation and maintenance, impact of development, political and legal constraints, and water quality. The criteria are organized in a decision matrix that provides a total score and rank for each potential water source. There are many different sources that can be used to supply water for domestic use, but only five are considered for NRWS due to their popularity within the Nilgiris District: rooftop rainwater harvesting, check dams, reservoirs, springs, and dug wells.

The development of simulation models within the water source yield module for the rainwater harvesting and check dam sources involved gathering local hydrological data. An extensive database of precipitation data was developed for the Nilgiris District, including 19 rain gauge stations spread evenly across the district. It was discovered that three distinct precipitation regions exist which are influenced to a different degree by the dominant northeast and southwest monsoon periods. As such, point precipitation data for villages throughout the district were calculated based on their location within one of the three regions. The methodology used for developing streamflow was analyzing the baseflow recession constant during the dry season. Since it is only during the dry season

that streamflow is significantly reduced, the critical factor is assessing the rate at which flow decreases.

A general application of the rooftop rainwater harvesting simulation was applied to ten villages throughout the Nilgiris Distract. One important discovery was that the village of Masinigudi, which lies in a rain shadow and receives the lowest level of annual rainfall in the district, performed to the same level as villages with a high annual rainfall. Since the region surrounding Masinigudi is deprived of water sources such as mountain streams and dug wells, rainwater harvesting may be a feasible and economically viable solution. Next, the entire DSS was applied to a specific case in the Emerald Valley village within the Red Hill micro-watershed. Three sources were considered including rainwater harvesting, check dam, and reservoir. After completing the DSS and viewing the decision matrix, it was found that the check dam source was the most feasible source to implement. The significant factors influencing the decision were a low capital cost and higher water quality level.

Water resources rely on a fine ecological balance to ensure a sustainable supply is available to future generations. Over the past fifty years, this balance has not been achieved in India with water resources showing rapid signs of depletion. The total renewable freshwater available in India dropped from 5277 m^3/person/year in 1951 to 1342 m^3/person/year in 2000: where a condition of scarcity is considered to be below one-thousand m^3/person/year (Lal, 2002). The government should play a central role in developing effective management tools that promote better decision-making in meeting the basic water needs of the people, while ensuring the longevity of India's water resources. As more strain is placed on river systems due to increased demand and industrial uses, coordinated activities are crucial to understanding the real impacts and developing a proactive plan for sustainability. The development of NRWS will hopefully provide an organizational structure that enables decision-makers to understand the impacts associated with different actions related to local water resources.

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"Nobody made a greater mistake than he who did nothing because he thought he could only do a little"
- Edmund Burke

TABLE OF CONTENTS

(Note: Appendices are located on inside back cover of thesis document)

LIST OF FIGURES

DESCRIPTION **PAGE**

LIST OF TABLES

DESCRIPTION **PAGE**

LIST OF ACRONYMS

The following acronyms are used frequently throughout this document:

CSWCRTI: Central soil and water conservation research and training institute

DSS: Decision Support System

GIS: Geographical Information System

HADP: Hill Area Development Program (government institution within Nilgiris District)

NGO: Non-Government Organisation

NRWS: Nilgiris Rural Water Supply (referring to the name of the developed DSS)

O&M: Operation and Maintenance

PRA: Participatory Rural Assessment

RDO: Rural Development Organisation (partner organisation in India)

RWH: Rainwater Harvesting

TWAD: Tamil Nadu Water and Development Board

VBA: Visual Basic for Applications (for computer programming)

WEAP: Water Evaluation and Planning System

WHO: World Health Organisation

WSHG: Women Self-Help Group

1 INTRODUCTION

1.1 Sustainable Water Supply

The Millennium Development Goals created by the United Nations in the year 2000, hope to generate an international effort to fight poverty and disease. One of the goals related to water is to reduce by half, by 2015, the proportion of people without sustainable access to safe drinking water. Currently there are over one billion people worldwide without access to potable water; the majority live in Africa and Asia (De Villiers, 1999). The deficiency of economic wealth is one cause of this devastating fact, but poor water resource management also contributes. In India, the groundwater source is gradually depleting, limiting the ability of rivers and lakes to maintain water during the dry season (Lal, 2002). During heavy monsoon periods, water erodes the topsoil and transfers non-potable water to the oceans instead of regenerating the groundwater source. Water resource planning is essential in reversing this negative trend and developing feasible sources of water for domestic use that are aligned with local economic, social, cultural, and environmental conditions.

1.2 Project Description: Scope and Objectives

General computer software programs using various methodologies are often used to assist decision makers in selecting and designing rural water supply systems in developing countries. However, many of these applications are not effective since they require data that are difficult and time consuming to obtain and do not incorporate social and cultural aspects of local conditions. Computer programs are more likely to be successful if they take into consideration local factors with the idea of minimizing the need for gathering complex data, use models that are applicable to local conditions, and incorporate non-technical factors into the computer algorithms.

The overall purpose of this research is to develop a specific computer software program, in the form of a **decision support system (DSS)**, for the selection of rural water sources in the Nilgiris District of Southern India. The program titled **'Nilgiris Rural Water Supply' (NRWS)** only applies to villages in the Nilgiris District and is not applicable outside this region. A partnership was formed with the non-profit Rural development organisation (RDO TRUST) to integrate NRWS into the institutions that implement rural water supply projects in the Nilgiris District. Several questions this research attempts to answer are listed in the following points.

- Within a village that requires improvements to their water infrastructure, what is the most ideal water source to develop?
- Will the villagers and external funding agencies be able to economically fund and sustain the water source?
- What storage capacity is required for the villagers to obtain an acceptable supply of water?
- What treatment processes are required to obtain an acceptable quality of water?

NRWS is divided into six modules that represent different criteria used to evaluate potential water sources: water source yield, capital costs, cost and ease of operation and maintenance, impact of development, political and legal constraints, and water quality. Sub-modules within the first three criteria allow the user to calculate yield and costs for each potential water source being evaluated. Upon the completion of each criteria module, the user can view the results of the analysis to determine a feasible water source to implement. There are many different sources that can be used to supply water for domestic use, but only five are considered for NRWS due to their popularity within the Nilgiris District. The sources include rooftop rainwater harvesting, check dams, reservoirs, springs, and dug wells. In order to develop NRWS, several objectives are outlined to effectively achieve the goals of this thesis, including:

- describe how the DSS contributes to a community water management approach;
- gather useful hydrological data for the Nilgiris District of Tamil Nadu;
- research and develop the methodology for estimating the yield of each potential water source;
- research and develop the criteria used to compare potential water sources;
- develop the computer algorithms necessary to perform the required steps and connect all components of the DSS;
- create a user-friendly Microsoft Excel program using the Visual Basic for Applications (VBA) programming language; and
- conduct case studies in the Nilgiris District for testing purposes.

1.3 Project Products

The main product developed in this research is a DSS for rural water supply in the Nilgiris District called NRWS. The software tool uses Microsoft Excel to lay out the user interface and organize data within spreadsheets. The programming language used to connect the modules and create the algorithms of the program is Visual Basic for Applications. Within the 'Acceptable Yield' module of NRWS, a sub-module runs a rooftop rainwater harvesting simulation to determine ideal storage requirements and percent reliability of the system. Since the construction of rooftop rainwater harvesting units has become mandatory on all houses in the State of Tamil Nadu (Radhakrishna, 2003), the rainwater harvesting sub-module has been isolated in a separate software package. This software tool uses the same interface and algorithms as NRWS, but is used to assess individual households as opposed to villages.

The computing skills required to use the program are minimal and anyone familiar with the basic use of Microsoft Windows and Excel should have little difficulty running the program. A network of help menus is provided to assist the user in running the program, and the steps are logically laid out for ease of use.

1.4 Target Groups

NRWS is being developed to aid in the decision making process for the selection of rural water supply implemented by both government and non-government organizations. All development initiatives within the Nilgiris District are carried out under the guidance of the governmental organization, **Hill Area Development Program (HADP)**. Before 1995 the HADP focused on site-specific projects, but since then have taken the initiative to spatially merge all their activities into watershed management projects. The entire Nilgiris District has been divided into 75 macro-watershed areas, of which ten are being implemented between 2004 and 2008. The macro-watershed areas are subdivided into micro-watersheds of approximately 100-1000 hectares (Jain, 2004). The purpose of the four-year projects is to meet the basic needs of villages, while improving the environmental stability of the area. The projects attempt to bring together all government departments and **non-government organizations (NGO)** into a cohesive unit that maintains transparency in order to implement works and activities that have the most benefit. One NGO is assigned to each watershed area to coordinate the efforts and act as a link between the government departments and village water association.

The government department directly responsible for rural water supply is the **Tamil Nadu Water Supply and Drainage Board (TWAD**). Depending on the location of the village, other departments get involved such as the Forest Department, and the Agricultural Engineering Department. If a village is located near forestland owned by the Forest Department and a feasible source is a stream in the forest, this work can only be carried out by the Forest Department. For this reason, a cooperative effort from all government departments and the NGO is crucial for the success of a rural water supply project. Since NRWS is designed to evaluate all potential sources within one computer file, the NGO is responsible for inputting data into the program. One instrumental factor to consider is the empowerment of the local community in the decision making process. Even though the NGO and government departments facilitate the inputted data into the computer, the local community decides what potential water sources are available and the importance of each criterion. The literature review section of the report (Chapter 2) describes when and how NRWS would be successfully used within the watershed management projects.

1.5 Project Benefits

Currently there is no standard methodology for selecting village water sources in the Nilgiris District. Organizing the selection process into a user-friendly computer program will not only benefit the social and economic status of the villages, it will also improve the environmental condition of the watershed area. The economic, social, and environmental impacts are described in the following sections.

1.5.1 Environmental Benefits

One of the main goals of rural water supply planning is to ensure that the negative environmental impacts of implementing a water source are minimized. The following list encapsulates several key environmental benefits resulting from the use of NRWS in effective rural water supply planning:

- proper check dam structures reduce the erosive behaviour of high velocity water travelling through streams;
- running a simulation to develop ideal storage capacities for check dams minimizes the encroachment on the surrounding land;
- properly sizing rainwater harvesting storage units minimizes the amount of natural resources used for construction;
- finding feasible technical solutions other than drilling deep boreholes improves groundwater conditions;
- finding appropriate site locations for tapping into streams and springs minimizes the negative impact on the local flora and fauna; and
- choosing a suitable pump location or eliminating the need for a pump minimizes the noise pollution in the village and surrounding natural habitat.

1.5.2 Social Benefits

One of the overall goals of the watershed management projects is to involve the local community in every aspect of the decision making process. Even though the works and activities are supervised by the NGO and Government departments, the local communities must take ownership of the projects in order for them to be sustainable (Tideman, 2002). The following list describes the social benefits of involving the local population in the decision making process of a rural water supply project:

- develops the capacity of the local community to manage their own systems;
- develops the leadership and communication skills of members of the community; and
- provides employment to landless people, increasing their social status within the community.

In addition to the social benefits derived from involving the local community in the decision making process, the use of a DSS for determining rural water supply schemes can indirectly benefit the local region. These benefits include:

- the implementation of water sources that negatively affect downstream villages can be mitigated;

- the awareness of legal issues involving potential water sources can minimize the likelihood of breaking the law;
- using an effective software tool increases the likelihood of obtaining the ideal water demand of a community; and
- improved water supply and quality minimizes the diseases caused by contaminated water.

1.5.3 Economic Benefits

Effective watershed management projects provide countless benefits for improving the standard of living for the resource-poor and disadvantaged sections of the community. The small scale works and activities are micro-managed by female self-help groups who are provided with finances up to 20,000 Rupees (1 $ CDN = 36 Rupees as of March 11th 2005) to carry out the associated tasks. Works and activities greater than 20,000 Rupees are supervised by the Government Departments, but still use local labour which provides employment to community members. Also, improving the water resources of the targeted regions increases the productivity of local farmers, hence increasing the crop profitability.

Besides the economic benefits obtained from the entire watershed management projects, there are economic benefits that arise from improving the efficiency of the planning process for rural water supply as listed below:

- the total costs of implementing potential waters sources can be compared to determine an economically viable source;
- the costs of sustaining potential water sources through operation and maintenance can be estimated for feasibility purposes.

1.6 Thesis Structure

This thesis, presented in seven chapters, will guide the reader in identifying and understanding the importance of planning rural water supply systems and the need for a decision support system that effectively develops feasible water sources for villages in the Nilgiris District. The chapters are arranged as follows.

Chapter 1 – Introduction
Chapter 2 – Literature Review
Chapter 3 – Conceptual Model Design
Chapter 4 – Decision Support System Development
Chapter 5 – Application of Decision Support System
Chapter 6 – Conclusions and Recommendations
Chapter 7 – References

Chapter 1 has provided a brief description of rural water supply and the potential benefits of a DSS that aids in determining feasible domestic water sources at a village level. Having introduced the background for this thesis, a literature review is summarised in Chapter 2.

2 LITERATURE REVIEW

The literature review for this report is strategically sequenced to provide the reader with a macro and micro perspective on how the NRWS DSS will fit into the water management philosophy of the targeted region in India. The sequence begins with a general analysis of watershed management practices and proceeds to describe different software tools currently being used for water resource management. The topics include:

- watershed management methodology;
- rural water supply methodology;
- existing DSS in Civil Engineering; and
- existing rural water supply DSS.

2.1 WATERSHED MANAGEMENT METHODOLOGY

In 1995, the Indian Ministry of Rural Development initiated new guidelines to ensure that all area development programs be implemented on a watershed basis (Paul, Radhika, 1999). This new approach had a long term perspective to rejuvenate and sustain depleting water resources as opposed to initiating small scale projects to deal with short term demand. An emphasis was placed on taking measures today, to create a sustainable watershed in the near future. One definition of watershed management from an Indian resource was "the wise use of soil and water resources within a given geographical area so as to enable sustainable production and to minimize floods" (Tideman, 2002).

The HADP has developed a unique procedure for implementing watershed management projects that stem from the same principles used across India (Figure 1). One of the most important aspects of the procedure is taking measures to ensure an effective process for forming local watershed associations. This involves village level meetings, awareness programs, and **participatory rural assessment (PRA)** exercises. The purpose of the PRA is to assess the villager's perceptions about their problems and needs, and to determine the opportunities that exist for improvement. Through the PRA, information is obtained regarding the socio-economic status of the people within the watershed area. It is also important to empower the community to make decisions regarding the appropriate works and activities that should be implemented. Thus, the villagers help to prepare a specific action plan and identify the appropriate site locations for the watershed works and activities.

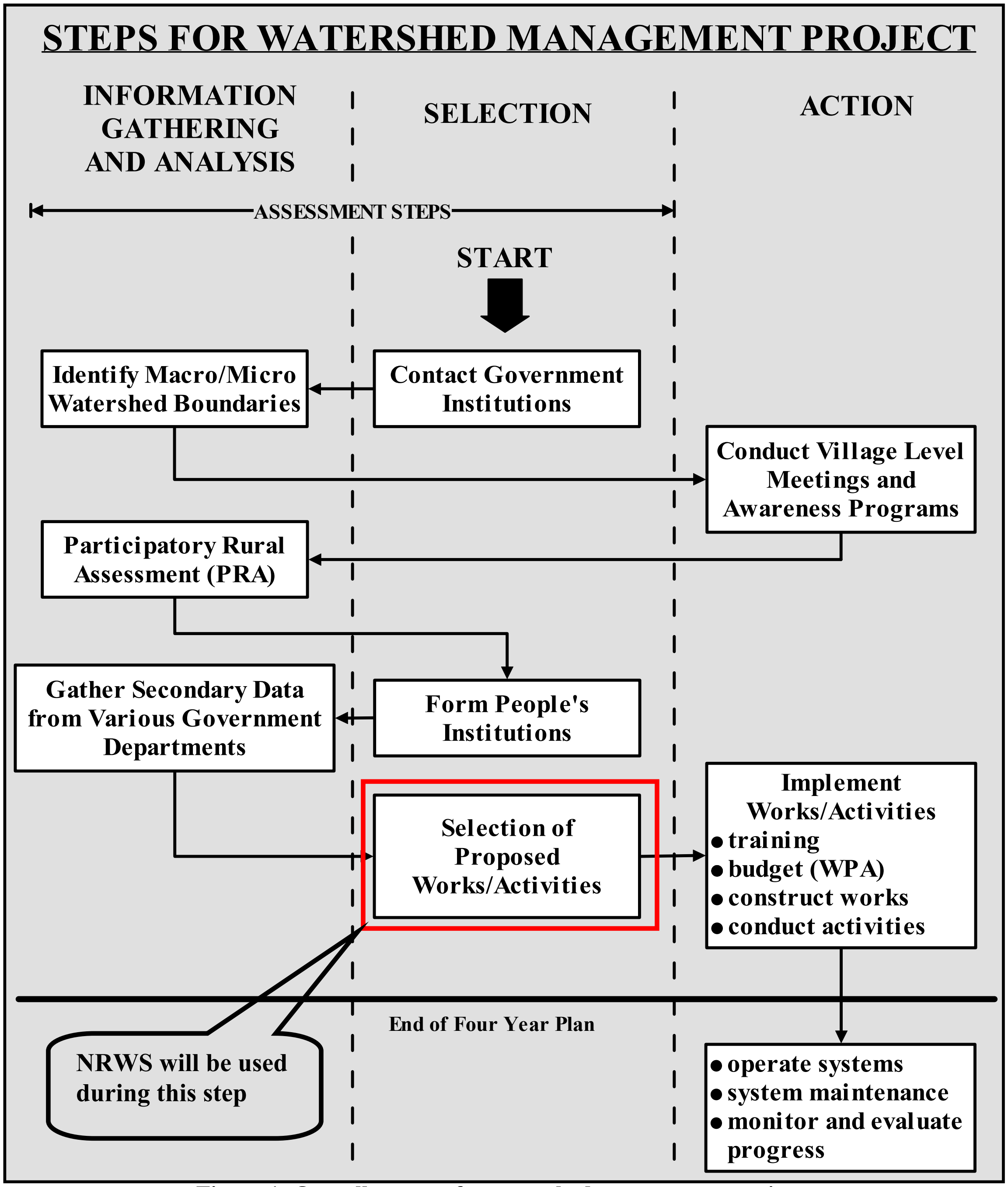

Figure 1: Overall process for watershed management projects

The PRA exercises are performed with all watershed stakeholders including farmers, landless people, women self-help groups, and the public. The exercises are described in the following list.

- **Transect Walk**- A transect walk is an observatory walk that helps the stakeholders understand the current condition of the watershed area. It is an effective exercise since one of the main causes of degradation within a watershed is the lack of awareness and education of the local population.
- **Time Line**- The purpose of the time line is to determine historical conditions and practices of the people within the watershed. It summarizes the changes over time as a sequence of events that have taken place in a particular village or area. The information pertains to the general history of the village or to sectors such as health, education, agriculture, and infrastructure.
- **Seasonality Diagram**- This exercise is conducted for the purpose of obtaining information about different occupations, cropping patterns, and agricultural operations during different seasons of the year.
- **Social Mapping**- In order to illustrate how the people identify their own village, a social map is constructed of the village. This exercise is carried out by the villagers using chalk to draw a map of the village on the ground. The map includes the main features of the village such as housing, temples, stores, electricity, and water sources. By conducting this exercise the people understand the social structure of the village as perceived by the entire group (Deverill et al, 2002).

The watershed management process is further described in the following four sections: community participation; engineering structures; reforestation initiatives; and domestic rural water supply.

2.1.1 Community Participation

For a watershed management project to be effective, the community must actively participate at every level to empower the community to make their own decisions. The fundamental principles of community technical management include (Lammerink et al, 2002):

- communities own the process of change;
- facilitators and local researchers participate in the community's project rather than leading them;
- increased management capacities are the basis for improved technical systems; and
- each watershed community develops its own specific management system.

With a sense of control and autonomy, people are likely to take pride in a watershed management project, increasing its potential for being sustainable. Therefore, the support agency is not the provider of technical goods, but the facilitator of processes to enhance the capacity of the community to manage their own technical systems. This enables community members to be active participants who are knowledgeable and accountable for their actions, which can be a catalyst for positive organizational change (Pasteur, 2002). Three case studies for water projects in Sri Lanka and India show a positive correlation between successful projects and high community-level social capital (Isham, Kahkonan, 2002).

Within the HADP watershed management projects, there are many different techniques for community participation including:

- forming community watershed associations and committees;
- forming **woman self-help groups (WSHG);** and
- educating the youth.

The NGOs working on the HADP watershed management projects organize a watershed association for each project being implemented. Any local community member living within the boundaries of the watershed area can become part of the watershed association. Each member must pay a fee of 25 Rupees which goes into a watershed development fund account, and is used for operation and maintenance after completion of the four-year project. Ideally, the watershed association represents all social-economic classes within the watershed to ensure the concerns of every community member are addressed. The association is registered as a society under the Society Act of India and operates as an advisory body at the micro-watershed level. A Watershed Committee is elected within the Watershed Association and its function is to work with the government departments and the NGO to carry out day-to-day activities of the watershed project. The watershed committee is also responsible for monitoring the quality of execution of the various tasks. There is one watershed volunteer within the committee that gets paid an honorarium of 400 Rupees per month. The volunteer provides assistance to the watershed committee, maintains the minute books and other records, and reports to the secretary on the progress of completed work.

The RDO Trust has helped develop more than 3000 WSHG within the Nilgiris District. The groups consist of approximately 15 women who work together on money-making initiatives such as farming and horticulture. Since tea is widely grown across the Nilgiris District, many WSHG own and operate a small plot of tea fields. The resulting profits are used to improve sanitation facilities and other socially responsible ventures. The groups are vital to watershed management projects because they empower the most vulnerable members of society to control their own development.

Education is important in creating awareness within the general public on the depletion of India’s water resources. Forming eco-clubs at schools provides students with the tools to minimize their ecological footprint. The three main areas of education include sanitation, hygiene, and water conservation.

2.1.2 Engineering Structures

One of the overall goals of a watershed management project is to effectively utilise precipitation by decreasing the amount of runoff and evaporation (Paul, Radhika, 1999). Water conservation measures decrease the amount of unutilised runoff by increasing the amount of surface storage or water infiltrating into the ground. Another important goal is to reduce soil erosion through sediment control which maintains the depth of topsoil in order to provide adequate conditions for growth of plant species in forests and agricultural lands. Reducing soil erosion also decreases the amount of particulate matter transferred to rivers, lakes, and reservoirs. Watershed management projects implement engineering structures to aid in decreasing runoff/evaporation, and preventing soil erosion. Some examples are provided in the following list (Jain, 2004; Tideman, 2002).

- **Check Dams**- These structures serve the purpose of preventing flow downstream by creating small reservoirs. The water can be used for domestic purposes, irrigation, or recharging the groundwater; depending on the permeability of the foundation.
- **Gully Plugs**- The main purpose of a gully plug is to prevent the deepening of gully beds and further erosion by excessive runoff. Gully plugs are gabion or loose boulder structures that reduce the velocity of runoff allowing soil particles to settle.
- **Percolation Tanks**- These tanks have a permeable layer that allows water to infiltrate into an underground storage tank. Water can also be directed from a check dam towards a percolation tank, or to a well for the purpose of recharging the groundwater.
- **Contour Bunds**- Contour bunds are embankments along contour lines that reduce the flow of surface runoff. They are used in agricultural land with poor internal drainage in order to provide crops with an adequate supply of water.
- **Contour Trenching**- Contour trenching involves excavating trenches along a uniform level across the slope of the land in the top portion of a catchment. The flow of excess runoff and silt can be controlled by the construction of trenches or depressions in the land. These structures reduce the runoff velocity allowing water to infiltrate into the ground.
- **Retaining Walls**- Retaining walls are used to stabilize the slopes of uncovered soil, reducing the probability of a landslide. They are typically used where soil has been excavated to build roads or foot paths, or used on agricultural land where vegetation is not strong enough to hold the soil structure.

- **Bench Terracing-** Bench terracing is a farming technique used on land with a steep gradient. The sloped land is terraced in a step-like manner to allow for increased infiltration and reduced soil erosion (Figure 2).

Figure 2: Effective bench terracing in Nilgiris District

Indicators can be used to monitor the effectiveness of soil and water conservation measures. Such indicators include keeping detailed information on water table level, streamflow, and precipitation data within each micro-watershed area. However, with limited economic resources, keeping track of extensive hydrological data is limited.

2.1.3 Reforestation Initiatives

One problem leading to the degradation of water resources in India is deforestation, where the per capita availability of forests is only 0.8 hectare (Lal, 2002). If a farmer's crop is not yielding profits, the farmer has no choice but to take measures to survive, which typically results in cutting down trees to sell firewood. Topsoil then becomes directly exposed to runoff, increasing soil erosion and causing high turbidity in the water. There are many examples in India where conserving forestland has prolonged the lifespan of groundwater sources leading to improved water resources (Lal, 2002). Reforestation initiatives are a key component of an Indian watershed management project, and must coincide with awareness programs to educate the community on the importance of preserving forest land.

The Nilgiris District is home to a vast number of native 'Shola' Forests that have reached equilibrium with local environmental conditions. 'Shola' vegetations are encountered above altitudes of 1500 metres and are restricted to the valleys or folds in the hills, while the surrounding hill slopes should ideally be covered with grasses. The 'Shola' Forests provide a natural setting for water conservation. Unfortunately, many of these forests have been converted into man-made Eucalyptus or Acacia forests which have a negative effect on the environment (Sharda et al, 1988). The Eucalyptus species not only extract all rainfall that enters the soil, but utilize an additional 100 millimetres of groundwater for every metre depth of soil the roots penetrate (Puri, Nair, 2004). Figure 3 provides a visual example of the differences between the 'Shola' and man-made forests. Since the acacia root system restricts the ability of other vegetation to grow, much of the ground does not have a vegetative cover causing great runoff. As a result, many trees become uprooted.

Figure 3: Left Picture- Shola Forest: Right Picture- Eucalyptus Forest

Within the HADP watershed management projects, an agroforestry program has been developed by the Forest Department and local residents. Agroforestry is defined as the sustainable use of forestland that maximises the yield of land and applies management practices that are compatible with the cultural practices of the local population. A forest should be capable of checking the erosion on any type of soil, on any slope, and under all types of climatic conditions. This will be accomplished by a forest with the following characteristics:

- dense population of trees;
- variety of trees;
- water availability; and
- healthy wild life and ecological balance.

2.1.4 Domestic Rural Water Supply

A balance must be created between the regeneration of water resources and the extraction of water for human use. Humans rely on water to live, and to sustain economic prosperity through the agricultural and industrial sectors. The major uses of water within the Nilgiris District are for domestic purposes, irrigation, and hydro-power.

For domestic use, a programme initiated by the Government of India and World Bank in 2004 redefined the policy for rural water supply on a 90/10 financing model (McKenzie, Ray, 2004). In other words, if a rural village could provide 10% of the funds for a water supply scheme, the government would provide the other 90%. The emphasis of this research is developing feasible sources of water for domestic purposes.

2.1.5 Summary

- Watershed management projects should encompass a holistic approach to improve the quality of life for all stakeholders.
- The concepts for change are rooted in empowerment and education to ensure project sustainability.
- Engineering structures should be implemented to reduce runoff and soil erosion which will recharge the groundwater source.
- Reforestation initiatives should be taken to create ideal land use patterns.
- Development of water resources for human use is strategically chosen on the basis of minimizing environmental impact while providing adequate supply.

2.2 Rural Water Supply Methodology

The previous section described the methodology used in India to undertake watershed management projects. A sub-project within the overall watershed management projects is the development of sustainable sources of water for domestic use. Residents of the watershed rely on water for drinking, washing clothes, cooking, and bathing. The need for a water supply project should be acknowledged initially by the local community. They can typically judge if the current water source is yielding an adequate supply, or whether the water is unfit to drink. There are several criteria that indicate if the source of water is unacceptable, including: the water is of poor quality; the supply of water throughout the year does not meet the demand of the community; and the users feel the source is not accessible. NRWS will play a key role in evaluating potential sources. In order to better understand the role of NRWS in developing domestic water sources, the associated steps are sequentially presented in Figure 4, and described in the following sections:

- assess existing water infrastructure and demand;
- collect background information;
- formulate alternatives and select water source;
- implement the water supply system;
- operate and maintain the water supply system; and
- evaluate and monitor the water supply system.

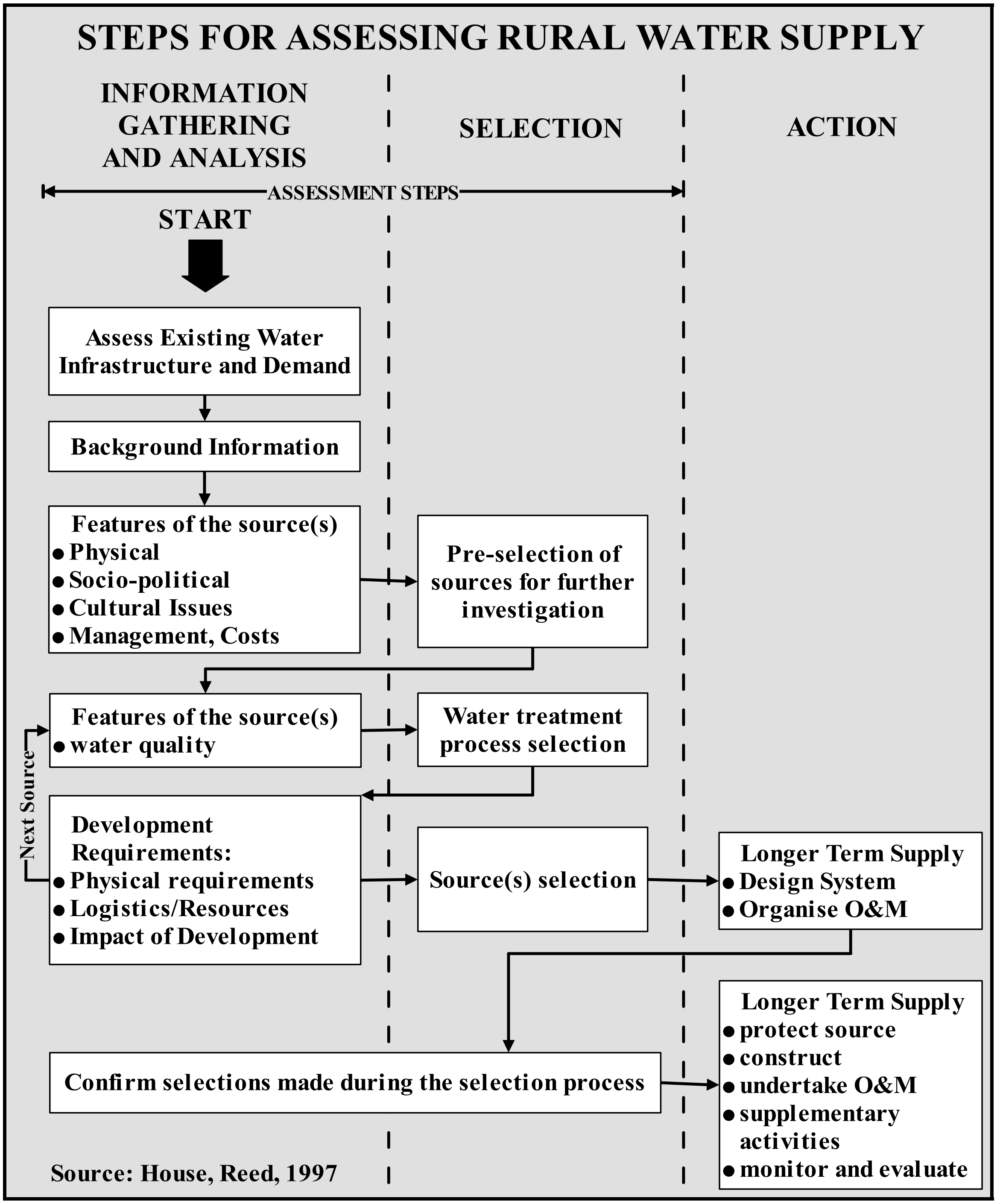

Figure 4: Overall steps for rural water supply management

2.2.1 Assess Existing Water Infrastructure and Demand

In order to assess a potential change in rural water supply, a problem must be internally recognized within the village community. The need for improvements can be established on the demand-side by understanding the expectations of the villagers, and the assessment of the physical conditions of the existing water infrastructure.

The perception of water demand by village officials can often be misguided and not representative of the general population. Determining an accurate water demand is crucial in understanding the need for improved services. PRA activities similar to those in Section 2.1 can accurately depict the views of every member of the community in order to develop a true representation of water demand. Demand is an informed expression of desire for receiving and sustaining a water supply and should satisfy the following evaluation criteria (Deverill et al, 2002):

- the value of water as perceived by the local population, not using external assumptions;
- the users should play a key role in deciding the service and service level they require;
- water demand should be applicable to vulnerable groups and individuals who are often excluded from the decision making process, in particular women;
- the process should be practical, with expressions of demand being used as a tool to guide potential water infrastructure design.

Evidence for requiring improved water services can also be established by analysing the existing water infrastructure. Observing the taste, colour, and turbidity of the current water supply can indicate problems in water quality. Water quality can also be assessed by noticing trends in waterborne diseases within the village. The need for improved water services without initially assessing water demand can also be identified if there is a distinct season which completely dries up the current water source.

2.2.2 Collect Background Information

Once a need for improved water services has been identified within the village, background information is collected which contains local environmental, social, and economic conditions. A list of potential data includes:

- **Local Development History**- reviewing the local development history utilises traditional methods, at the same time preventing mistakes that have been made in the past.
- **Environmental and Geographic Factors**- Some factors that help in choosing a potential water source include precipitation data, streamflow rates, and groundwater conditions.
- **Available Resources**- Utilising resources within the local community promotes every facet of sustainability. The use of local materials promotes environmental sustainability by decreasing the air pollution caused by transportation. Using local labour is socially sustainable in providing jobs to local citizens, and economically

sustainable due to the lower cost associated with hiring locals as opposed to outsourcing to larger companies (Batteson, Davey, Shaw, 1998).

- **Local Customs**- Local customs should be identified since water preferences may be directly linked to social/religious ideals.

2.2.3 Formulate Alternatives and Select Water Source

With limited knowledge, it is difficult for a community to make decisions regarding water source alternatives and their associated benefits. An uneducated community most likely does not have the technical capacity to make suggestions on potential sources. One approach is to take an exposure trip to a nearby completed project to allow interaction between villagers for the purpose of transferring knowledge (Deverill et al, 2002). This method is effective since local communities are more likely to communicate with one another, rather than with a government official. Once the community is aware of the potential sources available, an analysis is carried out using background information. In a collaborated effort, the stakeholders analyse the long-term economic, social, technical, and environmental impacts in order to decide upon an appropriate source to implement. This includes developing the design components, capital costs, and recurrent costs of each potential source for comparison purposes (Batteson, Davey, Shaw, 1998).

Both formulating alternatives and selecting feasible sources are components of NRWS, which is to be used as a tool to support the decision making process. The end decision ideally represents the view point of all users. Three case studies in Sri Lanka, Karnataka, and Maharashtra show that user satisfaction is increased by involving the community members in the design process and placing the final decision for source selection in the hands of the community (Isham, Kahkonan, 2002).

2.2.4 Implement the Water Supply System

Once the water source has been selected, a project plan is developed which ensures materials and labour are available when needed. This involves a number of components including:

- preparing plans for construction;
- determining sources of finance;
- determining sources of material; and
- implementing a schedule.

The use of local materials and labour should be maximized to decrease costs and build capacity within the community. Careful planning ensures that everything is present when needed, and that the job is completed within a pre-determined time period. The term ‘level of service’ describes the quality of service being used which is typically associated with physical features such as communal taps and in-house connections (Deverill et al, 2002), and should be decided upon by the local community based on the project's economic capacity.

2.2.5 Operate and Maintain the Water Supply System

Training local people to operate and maintain the system is essential for sustaining the technology. The critical technical requirements of a water supply system include (Davis, Brikke, 1995): skills; tools; standardisation; and consumables/spare parts. The technology used should match the skills of the villagers. If not, training courses must be provided for basic construction, pipe laying, pump repair, and simple water treatment. Tools and spare parts must be readily available to ensure malfunctions can be corrected as soon as possible. A storage house should be built to hold spare parts, tools, and any other materials used in the water supply system. Operation and maintenance is simplified by standardisation since uniform methods lead to familiarity among users and maintenance personnel.

In order for the operation and maintenance system to be sustainable, a steady flow of money must be available. One technique used to collect money is a user fee system based on fixed rates or a per volume rate. Communities must ensure that effective mechanisms are in place to monitor household contributions (Isham, Kahkonan, 2002). The villager's willingness to pay is based not only on household income, but also on other determinants such as the villagers perception of the importance of water (World Bank, 1993). Within the HADP watershed management projects, the Rs. 25 Watershed Association membership fee is put into a bank account to be used for operation and maintenance purposes. This account is managed by the watershed committee who decides on the allocation of funds. Thus, it is important to provide management training programs to the watershed committee in addition to training for technical staff (Batteson, Davey, Shaw, 1998). To enhance the effectiveness of operations, compensation should be given to managers and their staff since an over reliance on volunteers potentially leads to the breakdown of local management organizations (Deverill et al, 2002).

2.2.6 Evaluate and Monitor the Water Supply System

The purpose of evaluating water supply systems is to determine initiatives that succeed and fail. By doing so, the community is able to learn from past mistakes and build their knowledge of rural water supply management. The key principles for creating a system to evaluate and monitor rural water supply projects at a community level are described as follows (Deverill et al, 2002).

1. **Simplicity and Ease of Use**
   Systems should be developed that take into account the capacity of the local community. Only important indicators should be monitored using tools such as flow charts and checklists.

2. **Use of Data**
   The information collected must be used to take corrective action such as improving current performance or future programming.
3. **Focus on Key Sustainable Issues**
   A focus should be placed on finding a balance between examining short-term concerns and dealing with long-term issues.
4. **External Links**
   While the underlying goal is to allow local management to identify their own problems and solutions, external agencies can play a significant role, depending on the local context:
   - by providing a timely, appropriate response to address problems that cannot be solved at a local level;
   - by assisting with the measurement of evaluation and monitoring indicators that require technical knowledge outside the abilities of the local community; and
   - by testing the efficiency of the "Monitoring and Evaluation" process being used.

The goal of sustainability in water projects is not only to ensure a community meets demand, but also to develop the vision, attitudes, confidence, commitment, and competence of all stakeholders (Webster et al, 1999).

2.2.7 Summary

- A water supply project is a long term commitment from the initial stages of recognizing a water supply problem, to ensuring the sustainability of the system.
- NRWS will fit into the initial stages of formulating alternatives and developing feasible water sources.
- The latter stages of a rural water supply project include implementing, operating and maintaining, and evaluating the water supply system.

2.3 Existing DSS in Civil Engineering

The first two sections of the literature review describe the context of NRWS within the entire watershed management process. This section reviews the use of DSS and describes numerous examples used in the field of Civil Engineering with an environmental context. A multitude of systems exist for helping engineers and planners address problems, but key differences make DSS unique. Management information systems are designed to address relatively structured problems whereas DSS are more flexible. Expert systems are used to solve specific complex tasks whereas DSS integrate a broader range of topics, addressing the problem from a macro perspective. The purpose of a DSS is to create tools that help maximize the efficiency of a decision-making process through the application of relevant knowledge (Churchill and Baetz, 1999). Decision support systems also provide the tools for making better decisions. These tools are normative and present a systematic quantitative approach rather than a description of how unaided decisions are made (Keefer et al, 2004). Challenges arise in developing DSS due to the complexities of integrating separate technologies, which emphasises the importance of cross-discipline collaboration.

Decision support systems enable planners to move away from set piecemeal solutions to a more integrated approach for making better decisions. Walsh (1993) specifies that decision support systems should be modular, interactive, address unstructured problems, and integrate a user interface, models, and databases (Figure 5).

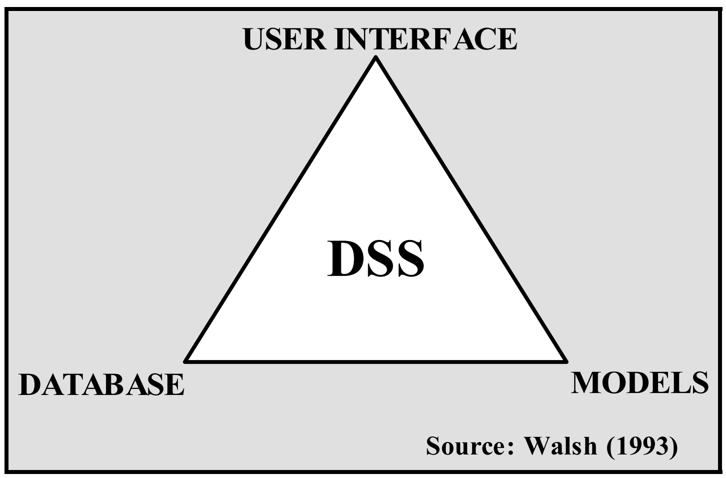

Figure 5: Conceptual framework for typical DSS

Applications in decision analysis were first documented in the 1970s. The general areas of application included energy, manufacturing and services, medical, military, and public policy (Keefer et al, 2004). During the early stages of DSS, applications were not interactive due to the inability of computers to perform complex tasks (Alter, 1977). During the period 1990-2001, increasingly powerful personal computer decision analysis software was developed, refined, and utilized in applications. This enabled the development of different layouts of DSS including (Keefer et al, 2004): problem structuring/formulation; strategy and/or objectives generation; probability assessment; utility/value assessment; and sensitivity analysis. In 1992 the concept 'value-focused thinking' described the use of values as the primary driver for problem structuring and analysis, including the generation of alternatives (Keefer et al, 2004). This concept transformed the idea of structuring a problem into developing strategies to solve the problem. In the early stages of DSS for water resource planning, the focus was placed on developing a pre/postprocessor for existing models to create a user-friendly interface for inputting data and understanding the outputs. This trend has shifted to integrating numerous models for understanding interrelated processes within entire hydrologic systems (Loucks and De Costa, 1990).

It is important within a DSS to effectively organize the structure into a clearly laid out sequence of events. With complicated problems, ideas can become scattered and unconnected. There are many flow chart tools that efficiently organize ideas to visualise the conceptual layouts of DSS including (Keefer et al, 2004): influence diagrams; belief nets; constraint networks; and decision trees. Belief nets are acyclic graphs containing a system of variables at nodes with directed links that are created through conditional probability tables. They are similar to constraint networks but use probabilistic relationships as opposed to constraints to link the variables. The most widely used tool is a decision tree which is a schematic representation of the relationship between decisions, risks, and outcomes. The branches of the tree break the overall system into simpler, independent segments. Decision trees are most appropriate where the problem type is broad and shallow. An influence diagram is a list of factors in a problem that are connected with arrows and signs showing the relationship between them. The influence diagram is similar to a decision tree but shows more dependencies among variables and does not show direct paths or scenarios.

2.3.1 Existing DSS for Water Resources

DSS are used in the area of water resources to help decision-makers address management issues at every level. Highly involved and integrated DSS combine the technical, social, and economic issues at a watershed level incorporating many hydrologic processes into one system. Others focus on specific issues relating to components of water analysis such as water quality. With the emergence of **geographical information systems (GIS)** in the late 1980's, water resource decision support systems shifted to integrating a spatial component into the generally accepted concepts of physical, environmental, economic, and social processes (Walsh, 1993).

As more strain is placed on river systems due to increased demand and industrial uses, coordinated activities are crucial to understanding the real impacts and developing a proactive plan for sustainability. Many generalized DSS have been structured to have the flexibility of adapting to the conditions of different watersheds such as Waterwear, RiverWare, WEAP, and other systems from Fredericks et al. (1998) and Shim et al. (2002). These DSS amalgamate the use of GIS, database technology, modelling techniques, optimisation procedures, and expert systems to address the wide range of issues within water resources as described in the following bullets.

- Waterwear was developed as a river basin planning tool to assess the needs of river systems across Europe. Its purpose is to assist government agencies in making better water resource management decisions (Jamieson, Fedra, 1996).
- Having a similar purpose but with more of a focus on groundwater modelling, a DSS for conjunctive stream-aquifer management was developed by Fredericks et al. (1998). Constructed around the generalized river basin network flow model MODSIM, this DSS integrates other applications such as GIS and the groundwater model MODRSP. It utilises groundwater response coefficients to model return

flow, streamflow depletion due to pumping, and the impact of hydrologic processes on stream-aquifer response over time.

- Eschenbach et al. (2001) developed a general river basin DSS called RiverWare that solves complex optimisation problems by specifying a physical and economic model of the system, listing prioritised policy goals, and indicating linearization parameters.
- Shim et al. (2002) developed a GIS-based integrated river basin flood control DSS that uses a real-time monitoring system to run simulation and optimisation models for reservoirs.
- The WEAP application, a GIS-based tool for integrated water resource planning, was developed by the Stockholm Environment Institute to provide a framework for policy analysis. The DSS functions include a water demand and conservation analysis, water rights and allocation priorities, groundwater and streamflow simulations, reservoir operations, hydropower generation, pollution tracking, ecosystem requirements, and project cost-benefit analyses (Levite et al., 2003).

Ito et al. (2001) stated that often generalized DSS for river basin management do not have the accuracy to incorporate the complex site-specific characteristics of different catchments. With this idea in mind, a DSS called CTIWM was developed for surface water planning of the Chikugo River basin in Japan using various models to describe hydrologic processes. Another site-specific DSS developed by Westphal et al. (2003) uses real-time hydroclimatic data to manage the reservoir system that supplies drinking water to the Boston metropolitan region. Four objectives that form the basis for the DSS are: maximise water quality, maintain ideal flood control levels, optimise reservoir balancing, and maximise hydropower revenues (Westphal et al. 2003).

A popular method for irrigating crops in Southern India is constructing a small-scale reservoir across the slope of a valley. From the reservoir, water travels through many canals irrigating the bordering plots of agricultural land. The allocation of water depends on many factors such as hydrologic flow into the reservoir, types of crops being irrigated, area of agricultural land requiring water from each canal, etc. A DSS was developed for the operation of tank irrigation systems in the state of Tamil Nadu in India (Arumugam, Mohan, 1997). The DSS incorporates heuristic, subjective, and judgmental information, and is used by operators for assessing real time allocation of water from the reservoir to different channels for irrigation purposes. Hydrologic processes from one case study were used to develop the algorithms of the program, but simple changes can be made to generalize the DSS for use in other tank systems.

Focusing specifically on water quality issues, Chen et al. (1999) developed a DSS called WARMF (Watershed analysis risk management framework) for calculating total maximum daily loads of various pollutants. Its purpose is to determine realistic scenarios for the allocation of pollutants to meet the water quality guidelines of a local region, in order for regulatory agencies and local stakeholders to negotiate a plan that suits all parties involved. The DSS includes a watershed simulation model, a database, and a consensus building module. Through the application of WARMF it was found that a more integrated tool was needed that incorporated the negotiation and compromise processes (Chen et al, 2004). Improvements were made to WARMF through the creation of a framework that supported decision making in a collaborative way. The consensus module was shaped to allow stakeholders to formulate, evaluate, modify, and vote on alternatives, and a web-based tool was developed for concerned citizens to voice their opinions and participate in management decisions (Chen et al., 2004).

2.3.2 Existing DSS for Waste Management

At a municipal level, the management of waste is broken down into five stages: collection, transfer, separation, treatment, and disposal. Solid waste planners and policymakers in the public sector develop programs to organize the transfer of waste through the five stages. It is a daunting task to find a balance that minimizes costs, reduces disposable waste, and minimizes greenhouse gas emissions through efficient truck routing schemes and appropriate treatment manufacturing processes. Inefficiencies in complex systems like these are mitigated through the development of decision support systems that can integrate all governing factors. Within the scope of a DSS, users are typically able to perform highly computational optimisation procedures without an advanced knowledge of mathematical programming. A number of DSS are used throughout the world to effectively develop systems for solid waste management (SWM).

Harrison et al. (2001) developed a DSS in the United States that quantifies life-cycle inventory of a range of pollutants, and develops costs for municipal solid waste programs. Structured in Microsoft Excel using VBA computer code, the user inputs data for chosen unit processes listed under each of the five SWM stages. The user can interactively explore potential strategies through an optimisation program that utilises cost and environmental objectives specified by the user (Harrison et al. 2001). Many important processes within SWM are outside the scope of this DSS including: planning transitions between SWM programs, optimal facility siting and vehicle routing, and optimal design of unit processes (Harrison et al. 2001). A very similar DSS was developed by Fiorucci (2003) for application in Italy. It determines the ideal number and types of plants for recycling, composting, incineration, and landfill, based on defined local refuse flows using the optimisation software Lingo. Along with cost functions that minimize recycling, transportation, and maintenance costs, constraints are used that take into consideration regulations for minimum requirements for recycling, incineration, and landfill conservation (Fiorucci, 2003). For example, the Government of Italy established a policy that 35% of all waste must be recycled. This approach may not minimize costs, but ensures the reduction of adverse environmental impacts.

Waste products resulting from manufacturing processes have three potential paths. Ideally, the waste is used as an input to another manufacturing process if it can be processed to meet specified guidelines. Otherwise, the waste is treated and recycled, or disposed of as a last resort. The prototype DSS developed by Boyle and Baetz (1997) addresses the potential for creating integrated industrial parks that feed off each other's waste products to produce efficient systems that minimize costs and environmental impacts. The user-friendly DSS matches the outputs of specified manufacturing processes with the inputs for other processes through the development of treatment trains that are based on a user-defined set of criteria.

2.3.3 Existing DSS for Urban Planning

Civil engineers play a crucial role in planning and designing urban centres that effectively provide essential services such as water, housing, and transportation. Decision support systems are often used for the purpose of choosing the most appropriate solutions that meet the needs of all stakeholders. Before a community has been developed, a location must be chosen. McIntyre and Parfitt (1998) developed a DSS for selecting appropriate residential land development locations based on a hierarchal structure of factors weighted on a predetermined scale of relative importance. Relatively new trends are incorporated into the DSS including: ecological and environmental awareness; social acceptance of land development activities; complex permitting process; and multiple plan reviews by numerous regulatory agencies (McIntyre, Parfitt, 1998). The flexibility of the DSS is limited since the factors are established by the program as opposed to the user. However, the users are able to assign weights and perform 'what-if' scenarios within the given criteria.

Once appropriate locations are selected for residential development, communities should be designed to promote social and environmental well-being. Churchill and Baetz (1999) developed a DSS for sustainable community design that utilises methodologies based on generally accepted rules for sustainable communities. Written in C++, the user is prompted for data including: Cartesian coordinates for topography that specify exclusionary zones; road orientation that maximises solar energy; road and sidewalk dimensions; an access point for the community; housing densities; and land-use characteristics. Sustainable community design rules are implied through input default values and incorporated into the program algorithms in order to create three-dimensional representations of ideal communities. The prototype DSS is limited to a grid layout and does not take into consideration slope and drainage, alleyways, and pedestrian systems beyond sidewalks (Churchill, Baetz, 1999).

Site-layout planning is a multi-objective problem that requires an open-ended structure for analysing unique factors. Tam et al. (2002) believe a non-structural fuzzy decision support system (NSFDSS) is appropriate for assessing these problems which have many potential factors. In addition to site-layout planning tools for designing communities, subsequent steps such as construction and implementation benefit from the use of DSS. To incorporate all parts of the site-layout planning process into one program, a generic NSFDSS was developed by Tam et al. (2002) to allow the user to choose appropriate factors for the site-specific conditions of a project. From a broad list of dominant physical and non-physical factors, the user chooses appropriate criteria in order to generate weightings based on human judgement. A pairwise approach is used to compare criteria on the same level based on three possibilities: one criterion is better than the other, equal, or worse. Through this simplification, a greater number of criteria can be compared without a great deal of complexity. Utilising output matrices for the pairwise comparison of the chosen factors, a total score is calculated indicating the most important factors.

Within urban areas there is a need for creating DSS that determine suitable infrastructure to deal with the flow of storm, waste, and drinking water. Sample et al. (2001) developed a DSS for urban storm-water management that carries out hydrologic and economic analysis on small-scale neighbourhoods. Based on a GIS framework, the DSS uses the SCS curve number method to estimate the amount of water travelling to the storm sewers based on land use and precipitation characteristics. Subsequently, a linear program establishes the economic framework for determining the optimal combination of best management practices. Due to simplifications and assumptions made, it is suggested the DSS be used as a guide as opposed to a solution provider.

2.4 EXISTING RURAL WATER SUPPLY DSS

Decision support systems have become common in the field of Civil Engineering for organizing and structuring problems in a way that improves the decision-making process. Engineers are learning the importance of taking proactive measures to addressing potential problems as opposed to reacting to problems as they arise. The DSS developed in this study focuses on the area of rural water supply in the Nilgiris District of South India. In order to set the framework for creating an original software package, this section goes into detail on past developments of rural water supply DSS. Since the techniques used for water supply in developed and developing countries are different, the tools researched in this section focus on DSS implemented in developing countries, in particular India. The software tools discussed include, THANNI, SimTanka, Jal Chitra, RWS DSS, and WATERCADE.

2.4.1 THANNI

THANNI (Tools for the Holistic Analysis of Natural Network Information) is a DSS for integrated watershed management that has been used in the Madurai District of South India which lies approximately 150 km south-east of the Nilgiris District. Developed in 2001 by the World Bank in conjunction with the Institute for Water Studies, Chennai (India), the DSS has a database that holds basic hydrologic, agricultural, and urban data for use in an optimisation model. A user-friendly interface is created through the integration of two software programs: Microsoft® Excel, and the GAMS optimisation package. By following a user defined set of hydrological, economic, legal and policy constraints, the DSS maximises the benefits of different water processes. In other words, the DSS attempts to allocate and control the amount of water used by different parties in order to sustain the local water resources. The allocation of water to potential users is particularly relevant in water scarce areas where demand greatly dominates supply. Many activities and services require water such as urban and rural domestic use, agriculture, industry, hydro-electric generation. Finding a split that satisfies each use is an overwhelming task.

It can be clearly illustrated that the uses of THANNI and NRWS are uniquely different. Although they were both developed in the State of Tamil Nadu for issues relating to water resources, THANNI addresses problems on a much broader and macro scope. THANNI runs on a monthly time series measuring variables such as inter-sectoral water allocation, cropping pattern, flows in the system, and reservoir operation. Its purpose is to maximize water use benefits through finding a balance between agricultural, human requirements, industrial, and sustaining reservoir operation. NRWS works within rural areas, specifically in the Nilgiris District, to develop feasible small scale water sources for domestic use. Extensive hydrological data is stored in databases for use in program algorithms, whereas THANNI has a generic structure for application in different regions of Tamil Nadu.

2.4.2 SimTanka

SimTanka is a modelling software program for rainwater harvesting that was developed by The Ajit Foundation in 1997. Its purpose is to determine the effectiveness and reliability of a given rainwater storage unit based on community demand.

The program requires monthly precipitation data from the previous 15 years to use as an indicator of the fluctuations in future rainfall. The user inputs community water demand along with a percentage that indicates how often the community wants the harvesting unit to perform within the required demand. The program calculates the minimum catchment area and smallest possible tank volume that can meet the water demand at the percent reliability requested. The runoff coefficient, which corresponds to the ability of the rooftop material to collect precipitation, is estimated from the type of catchment material being used. All the different combinations of input and output are described in Table 1. The safe demand represents the demand that can be met reliably by the rainwater harvesting unit.

Table 1: Different Options for Running SimTanka

	OPTIONS		OUTPUT			
	Area	**Tank Size**	**Area**	**Tank Size**	**Reliability**	**Safe Demand**
1	Yes	Yes	-	-	Yes	Yes
2	Yes	-	-	Yes Optimum Tank Size	Yes	Yes
3	-	Yes	Yes Optimum Catchment Area	-	Yes	Yes
4	-	-	-	Yes Optimum Tank Size	Yes Same as the user choice	Yes Same as the user choice

Source: Vyas, 1999.

NRWS uses six criteria to compare potential water sources. One of the criteria is water source yield which models the percent reliability of five potential water sources: rainwater harvesting, check dams, reservoirs, springs, and dug wells. The modelling component used to develop the yield for rainwater harvesting units is similar to SimTanka; however, there are three distinct differences. First, NRWS runs a daily simulation with ten years of data, whereas SimTanka runs a monthly simulation with fifteen years of data. Second, precipitation data for the Nilgiris District is stored in a database and utilised in the simulation according to a user-defined location. SimTanka requires the user to gather, develop, and input monthly data into the program. Thirdly, SimTanka provides a safe demand value for the simulation which NRWS excludes in order to maintain a generic template to compare all five potential sources.

2.4.3 Jal Chitra

Four years after the Ajit Foundation released SimTanka, it was found to be ineffective due to communities approaching their water resource challenges in a piecemeal manner (Vyas, 2003). Villagers were not benefiting from having a tool that isolated one water source. Another problem that separated the program functions from their applicability in the field was lack of consideration of non-technical issues. SimTanka only calculated the design parameters for rainwater harvesting units and did not incorporate the social aspects of the system.

As a result, the software program Jal Chitra was developed by the Ajit Foundation in 2001 for managing the water resources of a village. Continuous debate and dialog between the developer of the software, and its eventual user led to the creation of the conceptual outline for Jal-Chitra (Figure 6).

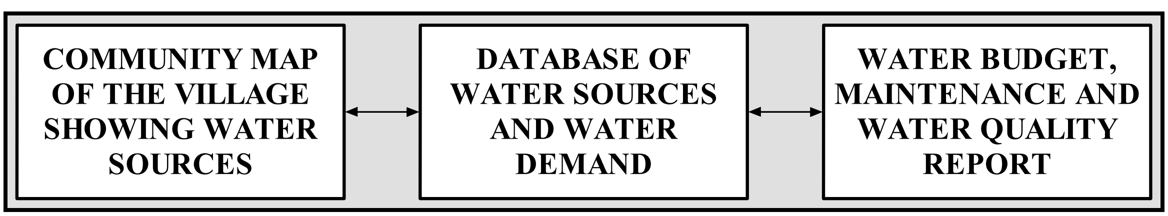

Figure 6: Conceptual Outline of Jal-Chitra (Vyas, 2003)

This outline is flexible in allowing the village to continuously monitor the state of their water resources. The tasks involved in using the software package include (Vyas, 2003):

- drawing an interactive community-based water resource map of the village;
- keeping a monthly record of the yield for each water source being used by the village;
- maintaining records on water quality through monthly testing;
- keeping records of required and past maintenance work;

- estimating the water demand for domestic, livestock, and agriculture uses as the demographics change within the village;
- generating future monthly water budgets based on past records;
- informing the community of the balance between groundwater use and recharge based on monthly water table levels;
- finding the reliability of covered rainwater harvesting systems using the SimTanka program; and
- estimating the amount of rainwater harvesting being carried out by the village and comparing it with the village's potential rainwater harvesting yield.

Jal-Chitra is being used by non-government organizations, and will be used in government schools once there is access to computers. As such, the program is designed to be compatible with basic computer hardware apparatus, and a low level of technical knowledge. One of the main advantages of using Jal-Chitra is to provide the tools that enable local villagers to have control over their water resources. Since the language used in the software is Hindi, a translation in the Tamil language would be necessary if applied to the Nilgiris District.

The software being developed in this thesis is used to evaluate potential sources based on calculated yields. It is effective at the beginning of a water supply project to ensure proper source selection is carried out. Jal-Chitra is a tool that continuously monitors current water resources and keeps records on the efficiency of the system. It is effective once a project has been implemented to ensure the sustainability of the project. Therefore, the software being developed in this thesis and Jal-Chitra can be useful at different stages of the project cycle.

2.4.4 RWS DSS

The software program Rural Water Supply (RWS) DSS was developed by the Institute for Water Research at Rhodes University in South Africa. It is a planning and design tool for sustainable rural water supply which covers technical, social, environmental, and economic factors. The project objectives are (Carmichael et al, 2001):

- to develop a standardised decision-making tool for evaluating options for practical application to rural water services provision;
- to create and develop the RWS-DSS for use in a Windows application; and
- to promote the use of the RWS-DSS for planning and evaluating future rural water supply projects.

The DSS emphasised small-scale, locally managed water supply systems and focuses on technical issues related to identifying appropriate technology and quantifying sustainable yields. The RWS-DSS was separated into six sections as described in the following list.

- **Water Supply Project Context**- The water supply project context registered the need of the target location and detailed the rate of success associated with their previous involvement in RWS projects. An assessment of the local knowledge was based on interviews and interactions between the rural community and project liaison.
- **Feasibility Studies**- The feasibility studies assessed technical considerations, institutional capacity, and the community's preference and capacity in relation to project costs and the ability to pay. The technical considerations included a comparison of water demand to existing water services and water use.
- **Detailed Survey**- The purpose of the detailed survey section was to gather adequate information on source yield/quality to process into quantifying feasible sources for implementation. The different sources analysed included rivers, reservoirs, rain catchment, springs, shallow/deep wells, and infiltration galleries.
- **Training**- The training section ensured that an adequate pool of local people had the necessary skills to participate in all stages of the rural water supply project planning and construction process. Thus, community members were equipped to take ownership for system operation, maintenance and monitoring. The DSS recorded the training modules required to develop the community member's skills.
- **Budget**- The budget section of the DSS derived total project costs to determine the economic feasibility of the project. The different costs included the decision-support costs of gathering information and conducting feasibility studies, and the long term costs of implementation, operation, and maintenance.
- **Business plan**- The final stage of the DSS was the business plan which summarised the proposed project for submission to potential funding agencies. The purpose was to present the information in a clear, easy to understand format, in order to increase the chance of receiving funding.

The shell of the DSS was developed in 2001 and the intention was to create RWS DSS for use within a Windows application, but the project lost funding and was never started. The theories and methodologies used in RWS DSS are not applicable to the Nilgiris District since they were developed for the conditions of rural villages in South Africa. In particular, the equation for estimating potential yield from the borehole source was established for application to double porosity fractured rock aquifers which are specifically found in Southern African environments (Carmichael et al, 2001). Similar approaches were used for other potential rural water sources.

NRWS uses similar concepts as RWS DSS, but focuses on evaluating the suitability of potential water sources based on a pre-defined set of criteria, as opposed to creating a computer program that organizes the logistics for developing rural water supply systems. The logistical structure in the Nilgiris District has already been established by the government and there is a need for a computer tool that promotes better decision-making within this structure.

2.4.5 WATERCADE

The need for a computer aided design and estimation software package for water supply systems in the Kerala State of India was established by the Socio Economic Unit Foundation (SEUF) in 2003. As a result, the computer program Watercade was developed to organize community water supply systems with an emphasis on pumping schemes (http://www.irc.nl/page/8127). A number of water sources commonly used in Kerala are incorporated into the program functions including dug wells, borehole wells, and reservoirs created through check dams. Trained personnel with basic technical knowledge can run the various features of the program which include:

- designing pumping schemes,
- developing water source characteristics and costing,
- economic sizing of the pumping main,
- positioning of valves with graphical aids,
- distribution system design, and
- material labour and data extraction.

There are a number of key differences that distinguish Watercade from NRWS, making each software package unique. Watercade provides the framework for designers to create complex designs, estimates and drawings with minimal data entry. If a village decides to implement a specific source, Watercade is useful for designing and costing the entire water supply system which involves choosing the technology for developing the water source, to designing a pumping scheme and distribution system. On the other hand, NRWS uses mathematical models to evaluate the appropriateness of different water sources before one has been selected. Another key distinction between the two programs is that Watercade incorporates conditions unique to Kerala State, whereas NRWS is designed for use only in the neighbouring Nilgiris District of Tamil Nadu. Since the two regions border one another, similar water sources are used for rural water supply, but the State of Tamil Nadu has recently focused on implementing rainwater harvesting units on community houses which is incorporated into NRWS.

2.4.6 Summary

- The purpose of this section was to review current water supply DSS software in order to set the framework for creating an original software package.
- THANNI is a large-scale water resource planning model that compares the water use of large cities and agricultural regions in the State of Tamil Nadu. Such a planning tool does not exist for promoting effective decision-making for small-scale rural water supply schemes. By developing NRWS, the process for selecting

rural water sources will ideally improve, increasing the success rate of projects in the Nilgiris District of Tamil Nadu.

- SimTanka was developed for the sole purpose of designing rainwater harvesting units for user-defined conditions. The Nilgiris District has many different water sources used for rural water supply, thus a system that isolates one source is not useful. Incorporating a simulation tool for rainwater harvesting within a framework that encompasses other sources and criteria would be beneficial. NRWS attempts to address these issues.
- Jal-Chitra is a tool for continuously monitoring the performance of existing village water supply systems in order to understand system deficiencies and take appropriate courses of action. It is useful in villages that desire to maintain existing infrastructure; however, it does not provide the framework for selecting new potential water sources. Poor decisions made at the planning stage hinder the success rate of rural water supply schemes. Therefore, even with the use of Jal-Chitra, there is still a need for providing a framework for better decision making at the planning stage.
- RWS DSS software was intended as a planning and design tool for sustainable rural water supply. The framework was developed but never implemented into a Windows application. A similar structure is needed in the Nilgiris District that focuses on local conditions and practices. As opposed to developing a system like RWS DSS for structuring the entire rural water supply process, a DSS is needed for the initial selection of water sources since a system is already in place for implementing projects.
- Watercade provides the framework for designers to create complex designs, estimates and drawings with minimal data entry. If a village decides to implement a specific source, Watercade is useful for designing and costing the entire water supply system which involves choosing the technology for developing the water source, to designing a pumping scheme and distribution system. This software program does not address the question of selecting the most appropriate source, which would be useful in the Nilgiris District.

2.5 A DSS FOR RURAL WATER SUPPLY IN THE NILGIRIS DISTRICT OF SOUTH INDIA

This literature review has shown that a considerable amount of knowledge exists for planning, designing, and implementing rural water supply schemes in developing countries around the world. Generic decision support systems and techniques are used to tackle the daunting task of providing water in areas that have poor water resources and limited financial capacity. Currently missing from the literature are site-specific decision support systems that utilise local hydrological and socio-economic data for assessing regionally based rural water supply issues. In the Nilgiris District of South India, an organizational structure exists for improving local water resources through watershed management projects that carry out initiatives to improve the conditions of forests, agricultural land, and villages. However, the tools used to make informed decisions are not effective, leading to poorly designed systems, in particular rural water supply schemes. The development of a DSS to help stakeholders make better decisions regarding the selection of village water sources is the focus of this research.

The conceptual model for the prototype DSS is described in Chapter 3. Currently there is no structured method for assessing potential village water sources in the Nilgiris District of South India. Many criteria are typically used to evaluate potential water sources and have been incorporated into the prototype DSS in the form of modules. These criteria are described along with the common water sources found in the district. Only relevant water sources are incorporated into the prototype DSS since one of the goals of the decision support system development is to base the framework on local conditions.

3 CONCEPTUAL MODEL DESIGN

In the previous two chapters, the need for a rural water supply decision support system (DSS) in the Nilgiris District was established within the context of the current government structure. The following chapter lays out the conceptual model for developing an effective DSS that suits the conditions of the Nilgiris District. This chapter describes the common water sources used for rural water supply and a methodology used for comparing them. There are six criteria used for comparing potential sources: water source yield; capital cost; cost and ease of operation and maintenance; impact of development; political and legal constraints; and water quality.

3.1 Sources For Rural Water Supply

Water travels on a continuous cycle through various physical states, making its way between the earth's surface and the atmosphere. The hydrologic cycle requires energy from the sun to evaporate surface water which is transferred to the earth's atmosphere. Condensation of water vapour in the atmosphere transfers the water back to the earth's surface in the form of precipitation. Once precipitation reaches land, it travels in a path of least resistance above and below ground. Vast networks of streams and rivers transport water into lakes and oceans for storage. A portion of the water infiltrates into the ground and is stored in underground aquifers or appears at the surface as springs. The complexity of the water cycle enables the potential for extracting water from a plethora of sources for rural water supply. Figure 7 describes the sources available through different components of the hydrologic cycle.

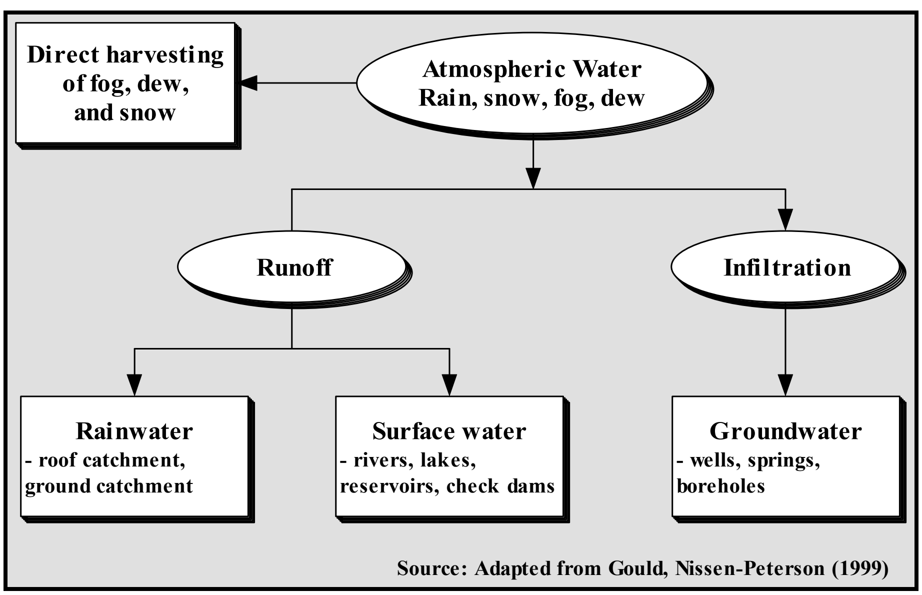

Figure 7: Origins of potential water sources for rural water supply

Ingenuity in dealing with water resources has thrived for thousands of years in India. Traditional methods of simple stone-rubble structures for impounding rainwater were used 5000 years ago in the Baluchistan District (Gould, Nissen-Peterson, 1999). In the late 1900's, initiatives were taken to implement large-scale projects such as constructing dams and drilling boreholes into deep aquifers. Recently, many rural establishments in India have resorted back to the traditional methods of collecting runoff and rainwater. In the state of Tamil Nadu, registration of boreholes has become mandatory and substantial fines are imposed for unauthorised sinking of wells (Radharkrishna, 2003). Although these regulations seem drastic, they are crucial for ensuring the sustainability of this precious resource. An emphasis has been placed in the Nilgiris District on recharging aquifers through water harvesting techniques as opposed to reckless exploitation of groundwater through deep boreholes. The check dam source has become very popular in the Nilgiris District, creating temporary storage reservoirs on small mountain streams from which water can be directly extracted. Check dams are ideal for use in a monsoon climate where there is a need to store surplus water from the rainy season for use during the dry season (Hanson, Nilsson, 1986). Rooftop rainwater harvesting has become mandatory by law in the state of Tamil Nadu (Radharkrishna, 2003). Even though the law is not strictly enforced, the source is gaining popularity in regions where a clean surface water source is not available. Table 2 outlines common rural water sources and their applicability to the Nilgiris District.

Table 2: List of water sources used and not used in the Nilgiris District

SOURCE	DISTRICT USE	CONDITIONS FOR USE/NON-USE IN THE NILGIRIS
Rooftop rainwater harvesting	**YES**	Not implemented on a village-wide basis, but used by many private homeowners as a secondary source. More popular in the plains region where other surface sources are unavailable.
Ground rainwater harvesting	**NO**	Not used in the Nilgiris District. More suitable for regions with low precipitation.
River	**NO**	Source not used in district due to lack of rivers and inadequate technology.
Lake	**NO**	There are no significant lakes in the district.
Reservoir	**YES**	Many large reservoirs exist in the district for hydroelectric generation but are not popular due to poor water quality
Check dam	**YES**	A very popular source in the mountainous regions. Not used in the plains.
Dug Well	**YES**	Popular in villages located in the valleys of the mountainous areas.
Spring	**YES**	Technology not well developed in the district for tapping springs, but source is still used sparsely throughout the district.
Borehole	**NO**	Strong government restrictions for implementing boreholes due to environmental consequences of depleting aquifers.

Only five sources of water are applicable to the Nilgiris District: rooftop rainwater harvesting, check dams, reservoirs, springs, and dug wells. From this list, the project stakeholders must select potential sources available to the village being assessed. Figure 8 illustrates a decision tree used to guide the user in choosing potential water sources.

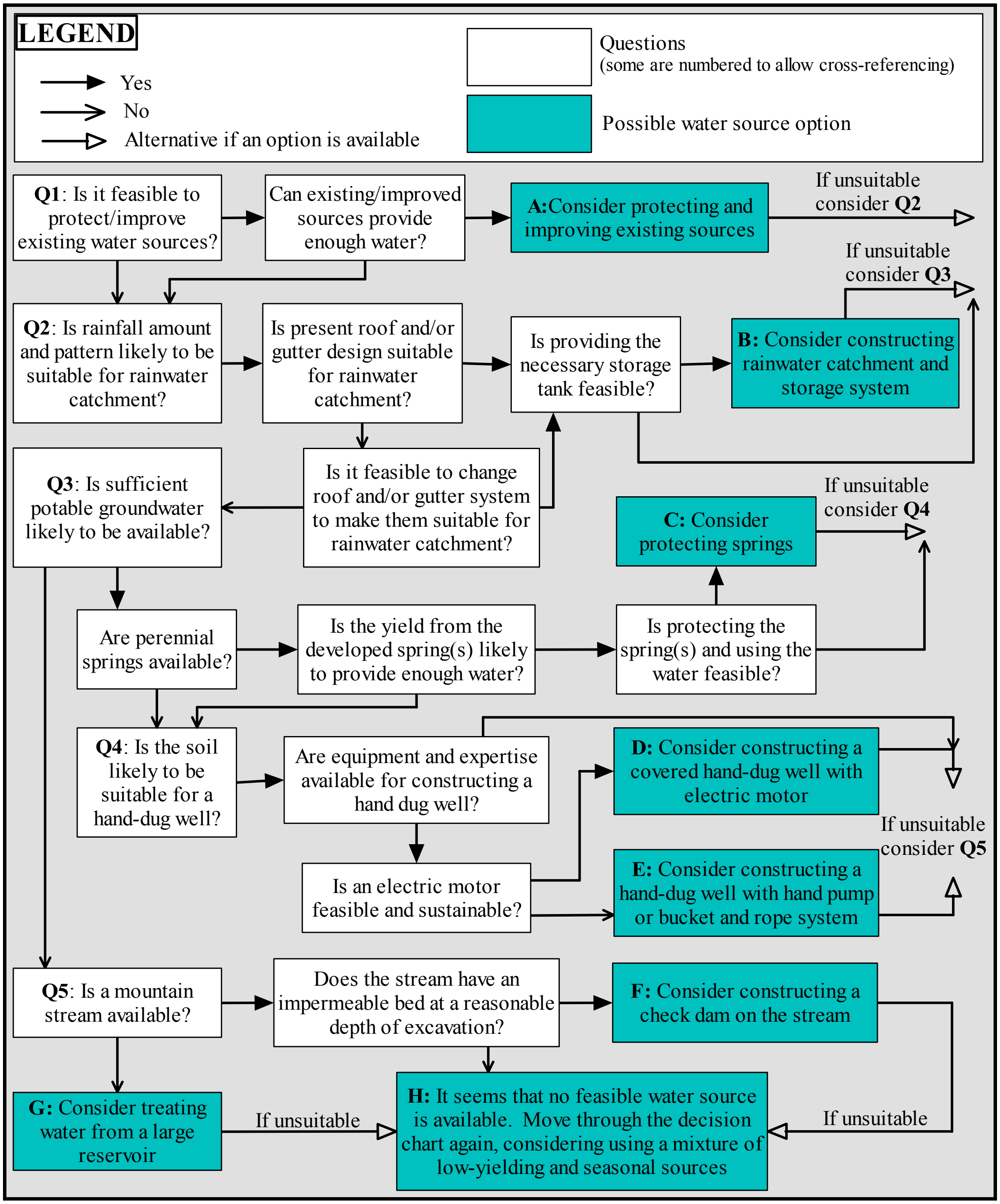

Figure 8: Decision tree for choosing potential water sources

3.2 CRITERIA 1-6: CONCEPTUAL MODEL DESIGN

Obtaining an adequate supply of water to meet village demands is typically viewed as a significant factor for assessing potential water sources. Due to substantially high levels of rainfall in the Nilgiris District, it is possible and realistic to store water above and beyond the desired demand. However, a crucial question must be addressed as to how the people view the importance of water in terms of their social values and economic capacity. Many people are willing to spend money on electronics such as televisions and cell phones, but are unwilling to view water as a vital resource worthy of financial commitment. In other cases, the ability to receive an adequate supply of water to survive is a daily struggle. These two extremes make it clear that public perception and economic capacity play leading roles in developing solutions for rural water supply. Therefore incorporating a wide variety of criteria into the decision making process is critical to the success of the rural water supply system. As such, NRWS will use six criteria for comparing potential sources: water source yield; capital cost; cost and ease of operation and maintenance; impact of development; political and legal constraints; and water quality. The steps used to select ideal water sources are illustrated in Figure 9.

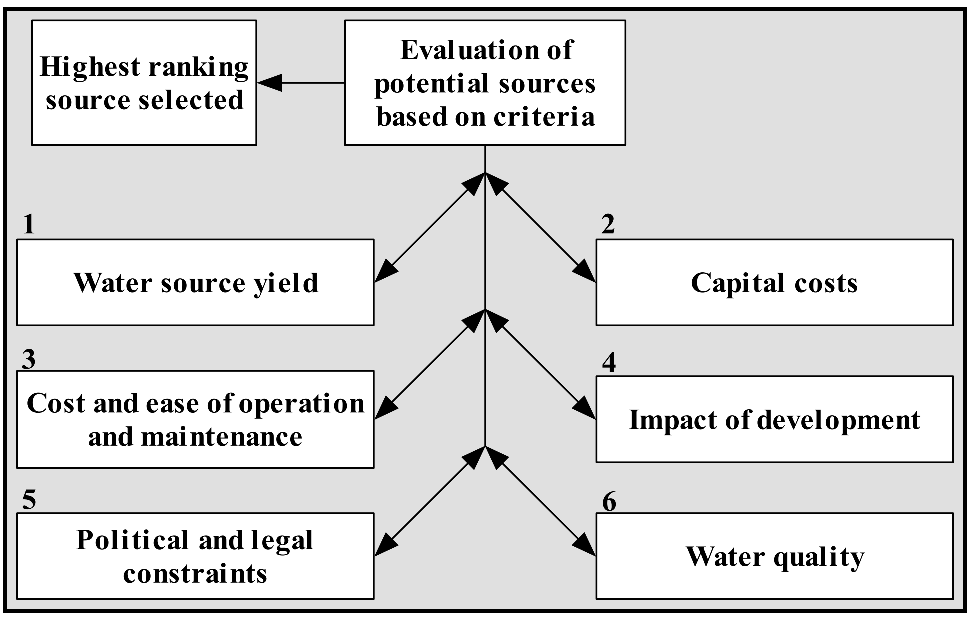

Figure 9: Criteria used in the process of selecting appropriate rural water sources

Criteria 2 to 6 address socio-economic factors that are developed through policies listing conditions and circumstances for selecting appropriate weights and scores for potential sources. Criterion 1 on the other hand is highly technical and quantitative in nature, using a number of equation-based techniques for estimating yields of potential water sources. Knowledge of the local hydrological data is useful for establishing water sources that will provide an adequate supply of water to a village. Rainwater harvesting techniques require precipitation data to determine how much water falls on rooftops throughout the year. Stream flow data during the dry season helps establish check dam specifications for required reservoir storage volumes. Inputs and outputs needed to properly assess the six criteria are presented in Table 3. Furthermore, since Criterion 1 uses quantitative methods for assessing the water source yield of every potential water source, the inputs and outputs for each source are displayed in Table 4.

Table 3: Overview of inputs/outputs for Criteria 1 to 6

Criterion	Input	Output
Water source yield	• village water demand • current village water supply • criterion weight and source scores	• total and monthly percent reliability for every potential water source
Capital cost	• quantity of materials required to develop each water source • criterion weight and source scores	• total capital costs for each water source
Cost and Ease of Operation & Maintenance	• operation and maintenance cost components for each water source • interest rate • willingness of villagers to pay in terms of rupees per house per year • criterion weight and source scores	• total annual costs (years 1 to 10) • total annual costs (years 10 to 20) • average annual costs • willingness of villagers to pay in terms of % of costs
Impact of development	• criterion weight and source scores	• identification of sources that have negative environmental impacts, or social impacts on the village
Political/legal constraints	• selection of sources to veto based on described conditions • criterion weight and source scores	• eliminating the vetoed sources from every module in the NRWS file
Water quality	• selection of water treatment processes required for each source • criterion weight	• water source scores based on water treatment process selection

Table 4: Overview of inputs/outputs for developing the yield for every potential water source

Water Source	Input	Output
Rooftop rainwater harvesting	• village location • rooftop catchment area • rooftop material • number of houses	• overall percent reliability • monthly percent reliability • village-wide storage requirement • average household storage requirement
Check dam	• region of check dam location • storage capacity of holding tank • initial stream discharge after dry season • ratio of reservoir surface area to depth • daily flow data at the beginning of extended dry period	• overall percent reliability • monthly percent reliability • reservoir storage requirement • recession constant • R^2 value for recession equation
Reservoir	• surface area of reservoir during dry season • greatest reservoir depth during dry season	• overall percent reliability • monthly percent reliability • reservoir volume • percentage of reservoir used by village over a six-month period
Spring	• same as check dam replacing reservoir with spring pond	• same as check dam replacing reservoir with spring pond
Dug well	• max. pumping rate (dry season) • max. pumping rate (monsoon period) • dry season length • dry season starting month	• overall percent reliability • monthly percent reliability

After assessing the six criteria for every potential water source, a scoring system is used to determine water sources that are suitable to implement in the village. First, a score between zero and ten is given to each water source based on its ability to perform within the respective criterion. For example, within the water source yield criterion, if a check dam source is projected to meet the demand of the village, and the rainwater harvesting source is not, the check dam source is given a higher score. Secondly, a weight between zero and ten is assigned to each criterion in order to differentiate their importance. If a village believes achieving an adequate water supply is more important than the impact of development, a greater weight is placed on the water source yield criterion. By multiplying the source score and the criterion weight, a number is produced that not only describes the attributes of the source within the given criterion, but also depicts its importance relative to all other scores across every criterion. And when the six weighted scores are summed for each potential water source, the total scores can be compared and ranked in order to determine ideal sources to implement. To ensure the scores are reasonable and accurately illustrate the local conditions, the following analysis should be taken (House, Reed, 1997).

1. Which source gives the highest score and which the lowest?
2. Compare the selected source(s) with the expected result by scanning the weighted scores. If they are different then investigate why.
3. Which key criteria are the deciding ones in making one options total weighted score higher than the others?
4. Could the lower scores be raised by undertaking additional activities to modify the situation in the field?
5. Would this change the final order of preference sources?
6. Look at the source(s) with the highest weighted score. Are any of the key factor scores tenuous or dependent on unknowns? If these sources are replaced by ones representing the worst scenario, would the order of preference change between the sources?
7. Undertake a 'sensitivity analysis': weightings and scores are modified slightly and the final positions compared. If there is no change in the overall positions then the results can be accepted with more confidence, but if there are variations, the results should be treated with care and further thought should be given to acceptable weightings and scores.
8. Is the order of preference sensible?
9. If so, choose the source with the highest weighted score. If not, reassess the scores and weightings for the particular scenario and repeat the process for comparison.

In order to develop a comprehensive tool for assessing rural water supply, research was carried out on methodologies used in developing countries and by international aid organizations working in rural locations. At the same time, site-specific research was carried out within the Nilgiris District to ensure the DSS would be applicable and meaningful to the local conditions. Working alongside government officials and non-government organizations directly involved in rural water supply enabled practices to be identified that were within the technical capacity of the stakeholders. The methodologies and algorithms used to develop the six criteria are conceptually described in the following sub-sections.

3.3 WATER SOURCE YIELD

Obtaining an adequate supply of good quality water is crucial to the health and well-being of the local population. If only one water source is being used to supply a village, water source yield is the most important criteria (Gould, Nissen-Peterson, 1999). Most of India experiences an extended dry season that lasts three to five months. It is during this time period that rural water supply systems fall short of meeting the demands of the village. Therefore, attempting to estimate the yield of potential sources minimizes the risk of water deficiencies after implementation. Criterion 1 requires two sets of data to effectively estimate the yield of each source: a generic village water demand throughout the year; and site-specific data for establishing water supply conditions for each source. With this data, the percent reliability can be calculated for every potential source in order to better judge their effectiveness in supplying an adequate quantity of water.

Water demand must be analysed from different perspectives to capture the true conditions of the village. Technically, a balance must exist between consumption patterns and existing/potential water infrastructure to understand if demand is being met. Economically, the villager's willingness to pay for the service based on household income and subsidies are a major contributing factor to assessing demand (Parry-Jones, 1999). Socially, water is a fundamental human need that should be addressed in the context of poverty, equity, and empowerment of low income groups (Parry-Jones, 1999). A minimum standard 20 litres/person/day was set by the United Nations during the International Drinking Water Supply and Sanitation decade between 1981 and 1990 (Gould, Nissen-Peterson, 1999). Through the Accelerated Rural Water Supply Programme, the Indian Government set 40 litres per capita per day as the normal water supply for rural communities (Department of Drinking Water Supply, 1986). Since the above guidelines differ in value, an emphasis is placed in NRWS on developing a realistic water demand that meets the needs of the villagers. A second factor required to effectively develop village water demand is accounting for continuing supplies from existing village water infrastructure. If a village is attempting to upgrade their current water supply system, the overall water demand remains the same. However, if a village desires a supplementary source to supply water during periods of low yield, the demand is adjusted to include only the amount of water required above and beyond the existing supply.

The second task within Criterion 1 is estimating the quantity of water available from the potential water sources on a monthly basis using various simulation and simplified deterministic models. Simulation models are most effective for developing the rainwater harvesting (RWH), check dam, and spring sources, whereas simplified mathematical equations are used to establish yields from the reservoir and dug well sources. After thoroughly developing the water demand characteristics for the village and establishing an estimate of water supply from potential sources, the overall and monthly percent reliability values can be calculated in order to compare the feasibility of each source.

Rainfall is abundant on a global scale, but its distribution in time and space is erratic, therefore careful design specifications are required (Gould, Nissen-Peterson, 1999). For this reason, a rainwater harvesting simulation model is used to calculate ideal storage requirements and percent reliability to minimize the effects of erratic distribution patterns. To better understand the rainwater harvesting simulation model, the storage unit can be described as the central processing module with numerous inflows and outflows. For each simulation day, if rainfall occurs, the respective volume captured by the rooftop is transferred to the storage unit. The volume of water consumed by the village is extracted from the storage unit on a daily basis. If the storage unit reaches its capacity after the inflow from rainfall and outflow from consumption, the excess volume of water spills over and is considered an outflow. The simulation runs 3650 times, representing ten years of daily information. A failure in the system occurs when the actual village water consumption does not adequately meet the ideal demand due to lack of water in the storage unit. The number of failures are accumulated and used to calculate the percent reliability of the system. Figure 10 illustrates the different components of the check dam simulation.

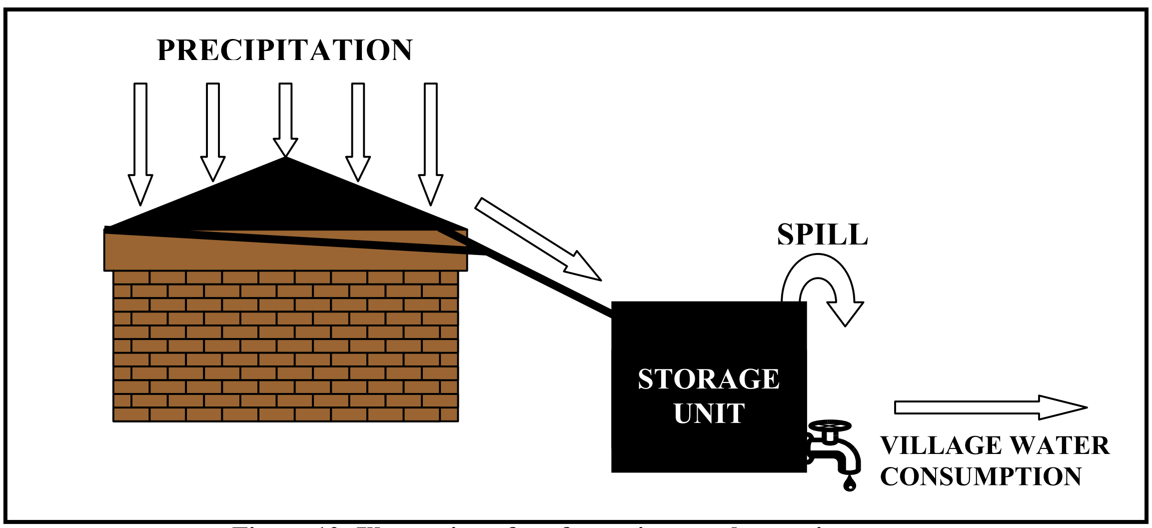

Figure 10: Illustration of rooftop rainwater harvesting system

The concepts used in the check dam and spring simulations are almost identical, the only difference being the terminology used to describe the storage system which is a reservoir and spring pond respectively. Check dams are implemented on small streams, whereas spring sources flow underground through a path of least resistance emerging as flowing water at ground level. Similar to the RWH simulation, the reservoir and storage unit combined can be described as the central processing module with numerous inflows and outflows. For each simulation day, the flow entering the reservoir travels to the storage unit until its capacity is reached. Additional flow remains in the reservoir, increasing its storage. The volume of water consumed by the village is extracted from the storage unit on a daily basis. If the reservoir reaches its capacity after the inflow from the stream and outflow from consumption, the excess volume of water spills over and is considered an outflow. With the proper implementation of spillways, damage to the check dam is minimized. The final outflow from the system is evaporation loss which decreases the volume of the reservoir based on the surface area and evaporation rate. Depending on the location, the number of simulation runs is between 112 and 158, representing the number of days in a dry period for different regions of the Nilgiris District. A failure in the system occurs when the actual village water consumption does not adequately meet the ideal demand due to lack of water in the storage unit. The number of failures are accumulated and used to calculate the percent reliability of the system. Figure 11 illustrates the different components of the check dam simulation.

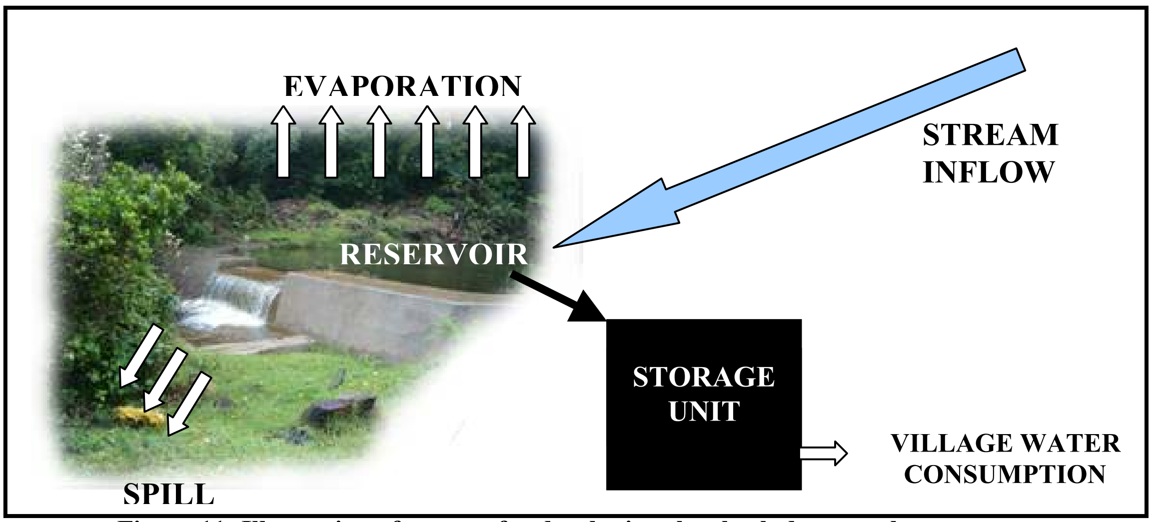

Figure 11: Illustration of process for developing the check dam rural water source

Large-scale attempts have been made in India to assess the groundwater conditions throughout the country. In 1982, the Government of India formed a "Groundwater Estimation Committee" which recommended that natural groundwater recharge estimation be based on the water table fluctuation method (Simmers, 1988). Relating this method to rural water supply, the analysis provides a macro assessment of recharge to a given aquifer, but it does not directly assess the design specifications for estimating an ideal well location. Also, establishing a well hydrograph with the water table fluctuation method requires flow measurements of wells that have already been constructed. This information is not available in the Nilgiris District for assessing small-scale rural projects. As such, a simplified deterministic method for estimating the yield of a dug well is used based on maximum pumping rates that maintain a consistent drawdown level. Site-specific pumping rates are ideal; however, an average from more than one nearby well is adequate due to economic restrictions. For low budget projects, utilising local knowledge of groundwater occurrences together with a vegetation survey can help identify ideal groundwater source locations (Batteson et al, 1998).

Another simplified deterministic model is used to develop reservoir yield based on its ability to supply water for a six-month dry season without recharge from precipitation. Water available to a rural village in a reservoir may diminish during the dry season making it important to assess dry season volume (Batteson et al, 1998).

3.4 Capital Cost

When implementing rural water sources, an emphasis is typically placed on matching the systems yield to the quantities of water required by the users, regardless of cost. In economically poorer countries like India, a greater emphasis is placed on finding financially viable water sources (Pacey, Cullis, 1986). Traditional systems based on lining an excavated pit with fired lime mortar were used over 500 years ago in India for collecting rainfall and runoff (Gould, Nissen-Peterson, 1999). Currently in the Nilgiris district, ferrocement tanks and concrete structures are used for rooftop rainwater harvesting and check dams respectively. Dug wells are encased by impermeable concrete caissons above the water table level and permeable concrete caissons below to permit a flow of naturally filtered water into the well. Water from a reservoir is extracted through an intake structure that is supported using an anchor and floating device where water is pumped through a pipeline into an above storage tank for distribution throughout the village. Spring water is stored in ponds with controlled spillways monitoring the overflow. Depending on the elevation of the source with respect to the village, water travels by gravity or is pumped to a storage unit located near the village. All of the standard water sources developed in the Nilgiris District use local materials and local labour which play a crucial role in deciding source feasibility.

Initial capital costs of water supply systems in the Nilgiris District are funded through two government programs and departments. TWAD is the central government organization responsible for the planning and funding of rural water supply systems. Recently, the HADP in the Nilgiris District has implemented area-wide watershed management projects to rejuvenate the depleting water resources through a combination of environmental, social, and economic initiatives. Part of the program's mandate is to improve village infrastructure which may include implementing new water supply systems.

All costing rates are taken from an Agricultural Engineering Department (2004) report and Sahu (2002) which use the 2003 and 2002 Nilgiris District Standardised Schedule of Rates respectively. Very common materials such as concrete, GI piping, masonry/ferrocement/plastic storage tanks, electric motors, etc., are used to construct the different water supply systems. The development of capital costs requires a site-specific analysis of the type and quantity of materials required to properly implement each source. Subsequently, a total capital cost can be derived for each potential water source to compare their economic feasibility.

3.5 COST AND EASE OF OPERATION AND MAINTENANCE

Due to financial burdens and inefficiencies, local governments in India are changing their role from providing services to facilitating processes (Davis and Brikke, 1995; Waughray, 2003). A similar trend has emerged in the Nilgiris District where the government still continues to fund the capital costs of rural water supply systems, but is limiting direct funds for operation and maintenance. As a result, villages must have the management, technical, and economic capacity to monitor their own systems. Successful water supply operation and maintenance programs require well-defined polices that effectively coordinate activities of the village organizations. Sustaining the operation and maintenance of a rural water source has two factors: actual cost of delivering the service, and peoples' willingness to contribute a yearly fee. Contributions from the local population strengthen the commitment of users to implement a sustainable system.

The first task in assessing Criterion 3 is developing the estimated costs required to properly operate and maintain each water supply system. Since the materials and services for operation and maintenance are standard for all sources, a set list can be used for this purpose. After establishing the estimated costs incurred over a twenty-year system lifespan, the willingness of the villagers to pay for the service must be assessed. The contingent valuation survey is used to develop an effective system for establishing reasonable yearly fees for operation and maintenance. The survey replaces guesses with a system that interacts with villagers to better understand what consumers want and are willing to pay (Altaf, Hughes, 1994). The next step is finding the local interest rate, and a resulting breakdown of yearly fees for different socio-economic classes from the contingent valuation survey. An interest rate is required to take into consideration the time value of money. For costs incurred on a yearly basis, an interest rate is not required since the funds are being collected and used in the same year. However, to avoid large fluctuations in yearly costs caused by a ten-year refit and twenty-year replacement of the system, these costs are distributed evenly throughout the twenty year life-span. Therefore, the yearly funds designated for future costs are able to earn interest in a bank account. The total yearly operation and maintenance costs and the percentage of costs the villagers are willing to pay can then be calculated. From this information, the project stakeholders can evaluate the pros and cons of operating and maintaining each potential water source. Along with the costs associated with operation and maintenance, the stakeholders should take into consideration the ease of operating and maintaining different systems. A system that requires pumping will require more technical knowledge than one without.

3.6 IMPACT OF DEVELOPMENT/POLITICAL AND LEGAL CONSTRAINTS

Very often the social and environmental implications of implementing water sources get overshadowed by the local technical and economic conditions. However, these social and environmental conditions can greatly hinder the success of a rural water supply system, and in some cases prohibit the development of a potential source. Criteria 4 and 5 address these issues in terms of the impacts of development and political/legal constraints respectively. Due to the qualitative nature of the criteria, they should be structured in a policy format to determine the adverse effects of developing each source.

Criterion 4 addresses the social, cultural, and environmental impacts that reduce the likelihood of developing a sustainable source of water. To assist the project stakeholders in assessing these factors, a list of generic questions enables them to be aware of potential impacts as described in the following points.

- Does the development of any potential water source have a negative impact on the religious beliefs or cultural norms of the village?
- Are the potential water sources accessible to all villagers, in particular, the elderly, children, and physically challenged?
- Is the displacement of existing community infrastructure necessary to develop any of the potential water sources?
- Does the abstraction from any potential water source impede the ability of nearby villages to sustain their current water source?
- Are any potential water sources located in regions prone to natural disasters (ie. flooding) where the infrastructure would not be able to maintain its structural integrity?
- If groundwater is being considered as a potential source, do pumping tests of nearby wells show a slow recovery of water levels or decreasing water table levels?
- Does the abstraction from any potential water source have a negative impact on the local flora and fauna?

Table 5 separates the water sources into unique sections which describe the impacts typically associated with the respective source.

Table 5: Impacts of development for each water source

WATER SOURCE	POTENTIAL POSITIVE IMPACTS	POTENTIAL NEGATIVE IMPACTS
Rainwater Harvesting	• Relatively easy to construct[1] • Environmental impact on surrounding water resources is negligible[2]	• Dependent on consistent supply of rainwater[1] • Space is required within the village for storing rainwater
Check Dam	• Good quality for surface water[1] • Reduces the need for pumping water[1] • Reduces the erosive behaviour of high velocity stream water	• Source may be inaccessible[1] • Upstream catchment may need protecting[1] • Encroachment of land caused by reservoir impacts local ecology • Reduces ability of downstream villages to meet ideal demand
Reservoir	• Generally easy to locate and assess[1] • Consistent water supply throughout entire year	• Difficult to protect source from contamination[1] • Excessive abstraction may restrict hydro-electric productivity
Spring	• High quality water[1] • Reduces need for pumping water[1]	• Source may be inaccessible or require extended distribution pipeline[1] • Source may move location over time
Well	• Better quality than surface water[1] • Consistent water supply throughout entire year	• Groundwater may be difficult to locate and assess[1] • Depletion of groundwater resources • Potential impact on villages using same aquifer

Sources: [1]Batteson et al (1998), [2]Gould, Nissen-Peterson (1999)

Criterion 5 is unique in that it is the only criterion that permits the project stakeholders to veto a source. There are two circumstances for which the veto clause applies: the water source is located on private property with an owner that will not allow abstractions; or, the water source is located in a conservation area owned by the government. Otherwise, the potential water sources should be compared based on the need for negotiations with landowners and government officials.

3.7 Water Quality

Approximately 80% of diseases and over one-third of deaths in developing countries are caused by poor quality drinking water (WHO, 1993b). Taking proactive measures to mitigate potential water quality problems is the best course of action for maintaining a safe drinking water supply. At the village level, three initiatives can be taken to improve conditions of water and health: implementing proper water treatment processes; developing an adequate sanitation system; and creating an educational program on hygiene and proper water use. There are two methods for assessing the need for implementing water treatment practices: qualitatively assessing the need for water treatment based on a list of physical conditions; or quantitatively measuring the important water quality parameters.

Assessing the need for water treatment processes can be effectively carried out through a qualitative sanitary inspection of the site-specific conditions of each potential water source. Such conditions may include the presence of latrines or animal husbandry practices upstream from potential sources causing microbiological contamination. Poor agricultural practices may lead to high levels of turbidity. Also, the presence of upstream industries may indicate high levels of chemical contamination which can be further identified through assessing the water's odour, taste, and colour. If certain conditions pertain to a potential water source, the appropriate treatment practice should be incorporated into the rural water supply system. Since only standard treatment processes are used in the Nilgiris District as described in Table 6, there may be cases where the water is untreatable. Such circumstances arise when the water is believed to have a high level of chemical contamination that would require an unaffordable, specialised process to treat.

Table 6: Standard treatment processes used in the Nilgiris District

TREATMENT PROCESS	DESCRIPTION	O&M SKILLS
Sedimentation	Water slowly travels across tank with weirs allowing particles to settle, reducing turbidity and microbiological contamination.	Low[2]
Slow Sand Filtration	Water is passed down through a designed sand-bed under gravity to reduce turbidity and microbiological contamination.	Medium[2]
Aeration	Introduction of oxygen to water to reduce taste, colour, and odour problems.	Medium[2]
Disinfection	Water is chlorinated or boiled to eliminate microbial contamination.	Medium[2]
Sari Filtration	Water is passed through a sari folded four to eight times[1] which has an effective pore size of 20 um.	Low

Sources: [1]Colwell et al (2003), [2]Batteson et al (1998)

The quantitative method looks more specifically at the levels of important water parameters to ascertain appropriate treatment processes. Three water quality features encompass all potential forms of contamination found in water including physical, chemical, and microbiological aspects (Table 7). A number of chemical and microbiological contaminants such as bacteria, arsenic, fluoride and other heavy metals can be directly harmful to health, while others such as colour, taste, and odour make the water unpleasant to drink.

Table 7: Potential water contaminants in drinking water

FEATURE	EXAMPLES
Physical	colour, taste, pH, odour, temperature, turbidity
Chemical	arsenic, chloride, conductivity, dissolved oxygen, fluoride, iron, manganese, nitrate, nitrite, sulphate, pesticides, heavy metals
Microbiological	bacteria, protozoa, viruses, helminths, higher organisms

Source: House, Reed (1997)

Identifying the presence of microbiological contamination in drinking water requires the measurement of an indicator organism that is easy to detect and enumerate. The most common indicators are thermotolerant coliform bacteria, in particular Escherichia coli, which can be detected in the field using the membrane filtration test (WHO, 1993b). Turbidity is measured in standardised nephalometric turbidity units (NTUs) which measure the scattering of light through a water sample. Measuring turbidity below 5 NTUs requires electronic meters, however, cost effective visual methods can be employed at levels above 5 NTUs (WHO, 1993b). The critical parameters to test for with limited economic resources are thermotolerant faecal coliforms, pH, and turbidity (WHO, 1993b). Table 8 shows the ability of each treatment process to effectively remove significant parameters, and conditions for treatment.

Table 8: Characteristics for standard treatment practices

TREATMENT PROCESS	CONTAMINANT REMOVAL PHYSICAL(P), CHEMICAL(C), AND MICROBIOLOGICAL(M)	CONDITIONS FOR TREATMENT
Sedimentation	• (P) 50% turbidity removal[1] • (M) 50% TCB removal[1]	• Average and maximum loading turbidity of 60 and 600 NTU respectively[1] • Average and maximum loading TCB of 1,000 and 10,000 respectively per 100mL [1]
Slow Sand Filtration	• (P) >90% turbidity removal[1] • (M) 95% TCB removal[1]	• Temperatures > 6 ^{o}C [1] • Average and maximum loading turbidity of 6 and 60 NTU respectively[1] • Average and maximum loading TCB of 50 and 500 respectively per 100mL[1]
Aeration	• (C) Precipitates iron and manganese[2] • (C) Lowers levels of volatile organics[1] • (P) improves taste/odour[4]	• Suitable conditions for exposing water to oxygen in order to cause oxidation reactions
Disinfection	• (M) >99.9% TCB removal[1]	• Average and maximum loading turbidity of <1 and <5 NTU respectively[1] • Average and maximum loading TCB of <3 and 25 respectively per 100mL [1] • pH<8 [1] • Maintain free chlorine residual of 0.5 mg/L with contact time of 30 minutes[1]
Sari Filtration	• (P) Removes particulate matter >20 µm [3] • (M) Removes micro-organisms causing guinea-worm[1]/cholera[3]	• Not available

Sources: [1]WHO (1993b), [2]Batteson et al (1998), [3]Colwell et al (2003), [4]House et al (1997)
Note- TCB: Thermotolerant coliform bacteria

The slow sand filter is an effective, low cost method of removing particulates and microbial contaminants given that the inlet water has a low enough suspended solid concentration not to clog the filter. An active biological community develops in the sand near the surface which captures organic particulates and microbial contaminants (Gadgil, 2004). Disinfection is the most effective method of treating microbiological contamination (WHO, 1993b). The concentration of chlorine usually required for disinfection is 100 g/ m^3 which can be administered using a dilute solution, bleach, or chorine powder (Skinner, 2003). To determine the required treatment processes for the quantitative method, a set of guidelines is used to assess the parameters that are above a permissible limit (Table 9).

Table 9: Water quality guideline for important parameters

Parameter	Suggested guideline levels		Possible Treatment Processes
	Permissible limit	Desirable limit	
Turbidity	10 NTU [2]	5 NTU [2]	Sedimentation, Slow-sand filtration[4]
Odour	Unobjectionable	Unobjectionable	Aeration[6]
Colour	25 Hazen units [2]	5 Hazen units [2]	Aeration[6]
pH	6.5-8.0 [2]	6.5-8.0 [2]	Raise pH- 1.0mg/L $CaCO_3$ Lower pH- sulphuric acid (avoid if possible)[6]
E.coli	< 10 thermolderant coliform/100 mL [1]	0 thermolderant coliform /100 mL [1]	Sedimentation, Slow-sand filtration, Disinfection[4]
Chloride	1000 mg/L [2]	250mg/L (aesthetic)[2]	No standard treatment available
Fluoride	1.5 mg/L [1]	1.5 mg/L (health) [1]	Filtering through bone char[4]
Cadmium	0.003 mg/L [1]	0.003 mg/L[1]	No standard treatment available
Copper	0.05 mg/L [2]	1.5 mg/L[2]	No standard treatment available
Iron	1.0 mg/L (health long term) [1]	0.3 mg/L (aesthetic) [1]	Aeration (precipitates from solution)[3] Slow-sand filtration (removes some)[6]
Lead	0.05 mg/L [2]	0.01 mg/L [1]	No standard treatment available
Manganese	0.3 mg/L (health long term) [2]	0.1 mg/L (health) [2]	Aeration (precipitates from solution)[3] Slow-sand filtration (removes some)[6]
Mercury	0.001 mg/L [2]	0.001 mg/L[2]	No standard treatment available
Selenium	0.01 mg/L [2]	0.01 mg/L[2]	No standard treatment available
Nitrates	100 mg/L as NO_3^- [2]	45 mg/L as NO_3^- [2]	No standard treatment available
Sulphates	400 mg/L [2]	200mg/L (aesthetics)[2]	No standard treatment available
Taste	Agreeable	Agreeable	Aeration[6]
Arsenic	0.05 mg/L [2]	0.01 mg/L (health)[1]	Batch-mixed iron treatment[5]

Sources: [1]WHO (1993a), [2]BIS (1991), [3]Batteson et al (1998), [4]WHO (1993b), [5]Ramaswami (2001), [6]House et al (1997).

The conceptual model described in Chapter 3 presents the ideas and concepts that are used to effectively assess the need for improved water supply systems, and for selecting appropriate sources based on local conditions in the Nilgiris District. In Chapter 4, the conceptual model is used as a basis for the development of an applicable decision support system that structures the problem in a user-friendly computer program based in Microsoft® Excel using the VBA programming language.

4 DECISION SUPPORT SYSTEM DEVELOPMENT

NRWS incorporates a broad spectrum of features into the DSS algorithms in order to fully grasp and encapsulate the factors that influence rural water supply in the Nilgiris District of South India. Chapter 4 attempts to clearly describe the wide range of methodologies used to develop each feature in order to explain the program functions. A complete set of computer algorithms for NRWS are provided in Appendix E. The first section of Chapter 4 summarises the general layout and flow of the program, starting when the user first opens the file to the end result of evaluating and choosing ideal water sources to implement. The remainder of the sections describe the modules within NRWS and also a number of important factors within Module 1 as listed below.

- **Module 1**: Water Source Yield
  - → Precipitation Data
  - → Check Dam Model
- **Module 2**: Capital Cost
- **Module 3**: Cost and Ease of Operation & Maintenance
- **Module 4**: Impacts of Development
- **Module 5**: Political/Legal Constraints
- **Module 6**: Water Quality

Within Module 1, the water source yield is developed for all potential sources, and two sub-sections focus on the methodologies used for the rainwater harvesting and check sources. For the rainwater harvesting source, an extensive database of precipitation data is developed for rain gauge stations across the district. The check dam source requires a method for estimating streamflow, and a number of methodologies are compared.

4.1 SCOPE AND GENERAL LAYOUT OF NRWS

Water resources rely on a fine ecological balance to ensure a sustainable supply is available to future generations. Over the past fifty years, this balance has not been achieved in India with water resources showing rapid signs of depletion. The total renewable freshwater available in India dropped from 5277 m^3/person/year in 1951 to 1342 m^3/person/year in 2000: where a condition of scarcity is below one-thousand (Lal, 2002). A 185 percent increase in population over this time period greatly contributes to this devastating fact, but is no justification for allowing the situation to reach its current state (ORG, 2001). The government should play a central role in developing effective management tools that promote better decision making in meeting the basic water needs of the people, while ensuring the longevity of India's water resources. As more strain is placed on river systems due to increased demand and industrial use, coordinated activities are crucial to understanding the real impacts and developing a proactive plan for sustainability. The advancement of computer technologies and data collection have helped synchronize organizational structures that enable decision makers to understand the impacts associated with different actions. NRWS, a computer program developed to help decision makers in the Nilgiris District assess rural water supply, allows the user to carry out a quantitative technical analysis of potential sources based on local data, and provides a qualitative framework for comparing sources. It is designed to encourage the user to take into consideration all factors in developing technically and economically feasible water sources which are socially accepted by the local community. Since the technical capacity of the users in the district is limited, NRWS focuses on maintaining a user-friendly interface, while masking the complexity from the user.

Since the process for assessing potential water sources is complex on a social, economic, and technical level, the organizations using NRWS must have a good rapport with the rural villages and effective mechanisms for village capacity building. As a result, NRWS is a decision support system for rural water supply as opposed to a specialised expert system used by highly trained individuals. The software program is used to assist a village in selecting a workable development option based on informed decisions. In other words, NRWS does not formulate an ideal course of action, but provides the user with information to better assess what course of action suits the needs of the village.

4.1.1 DSS Layout

NRWS aids in the process of identifying key issues in selecting sustainable water sources and systematically guides the user through various methodologies to quantify the potential water sources and assess other critical parameters. It is divided into six modules that represent six different criteria used to evaluate potential water sources: acceptable yield; capital costs; cost and ease of operation and maintenance; impact of development; political and legal constraints; and water quality. Sub-modules within the first three criteria allow the user to calculate yield and cost for each potential water source being evaluated. There are many different sources that can be used to supply water for domestic use, but only five are considered for NRWS due to their popularity within the Nilgiris District. The sources include rooftop rainwater harvesting, check dams, reservoirs, springs, and dug wells.

The shell of NRWS is developed through Microsoft® Excel using the Visual Basic for Applications programming language. A user friendly interface is established through a network of links and forms that clearly direct the user through the program functions. Help files for every module and sub-module are available through a customized menu to assist users when problems arise. Before entering into the main menu of NRWS, a form prompts the user to decide between opening a new village file or continuing with the existing file settings. If a new village file is created, the program automatically opens the 'save as' form to ensure the existing village file does not get altered. For simplification purposes, the main menu of NRWS acts as a hub for transferring between the six modules and the DSS results worksheet. The user can only access the modules through the main menu and cannot transfer between modules. If additional sources become available to the village after the initial file is started, they can be added through a user form on the main menu.

4.1.2 Criteria Evaluation Method

One underlying objective of NRWS is not to carve a specific path for the user to follow, but to give the user flexibility in assessing the needs of a specific village. It cannot be assumed that each village has the same set of ideals and conditions. As such, NRWS gathers and organizes the information necessary for quantifying water source attributes, but allows flexibility in how those attributes are perceived by the local village. The technique used for this purpose is developing a decision-matrix which involves the user inputting a weight for each criterion, and a score for each potential source within the criteria. This system lets the user apply greater influence to criteria that are more important to the village. By multiplying the source score and the criterion weight, a number is produced that not only describes the attributes of the source within the given criterion, but also depicts its importance relative to all other scores across every criterion. And when the six weighted scores are summed for each potential water source, the total scores can be compared and ranked in order to determine ideal sources to implement.

After completing all six modules, the user can view the DSS results in order to determine the ranking and total scores of the potential water sources. An 'incomplete' or 'complete' label is posted beside the module links on the main menu indicating the current status of the module. In the case where the user wishes to exclude a module due to its insignificance, a zero weighting must still be inputted to show the user is aware of the unused criterion. If any of the modules are listed as incomplete, the user is denied access to the DSS results. Otherwise, the results of the decision support system can be accessed through a link on the main menu. The user can view the results in table format which lists the weighted scores and ranking of each source, or can view the results in a bar graph that illustrates the significance of each criterion for each source (Figure 12).

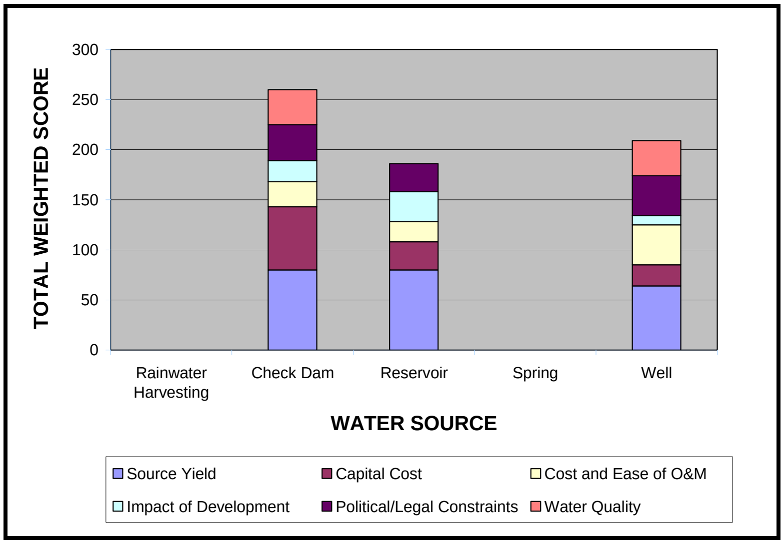

Figure 12: Results of the DSS in graphical format

4.1.3 Help Menu

Throughout NRWS, the user may come across criteria and program specifications that are difficult to understand. To assist the user in performing the different functions of NRWS, help-files are available for each module through a customised dropdown menu (Figure 13). The files explain the module components and thoroughly describe the activities required to gather all necessary input variables.

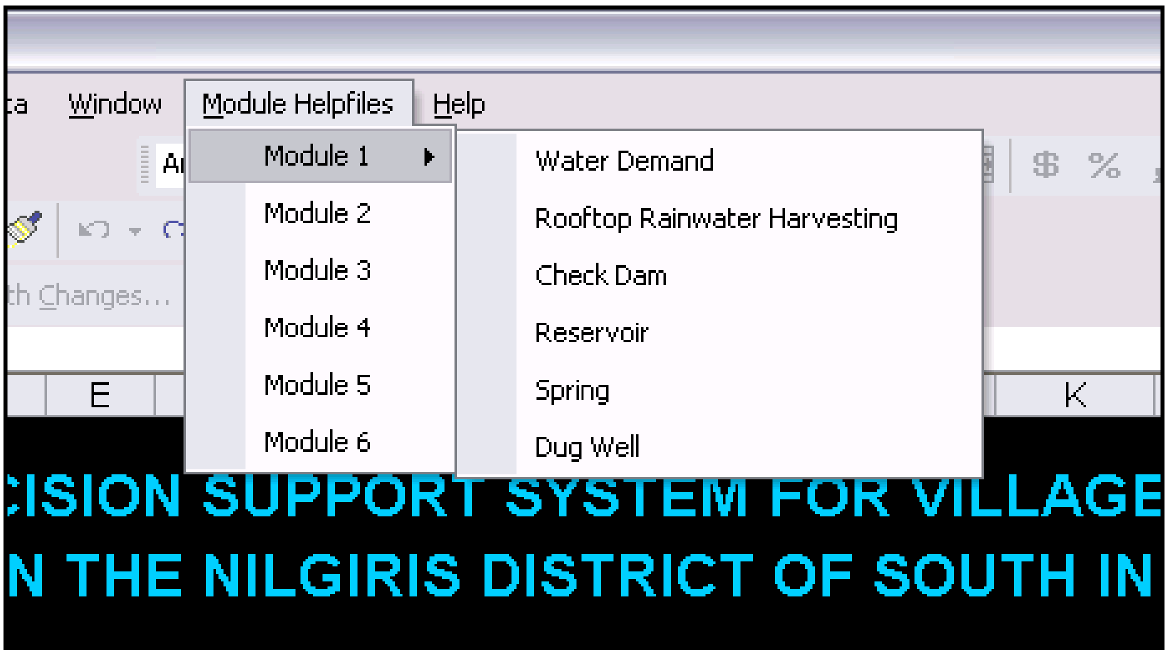

Figure 13: Help files listed on customised menu in NRWS

In order for the user to have access to the help-files, they must be placed in a file folder named NRWS under the Program Files setup on the main hard drive of the computer. Otherwise, an error message will appear when attempting to open the files indicating that the files are not available. The complete NRWS software package presented to the user will contain a 'readme' file that clearly describes the steps required to access the help-files. Appendix F contains the help files for every module and sub-module.

4.2 PRECIPITATION DATA

The average annual precipitation in the Nilgiris District widely ranges from 730 mm in the rain shadow of Masinagudi to 3515 mm in Nadugani. An elevated plateau that covers a majority of the Nilgiris District reaches a top elevation of 2600 metres a.m.s.l at the tip of Dodabetta peak (Meher-Homji, 1984). The sloped lands are mostly covered with tea plantations and forestland, whereas the valleys are cultivated with a wide variety of vegetables. The plateau rises abruptly from all sides of the plains which are situated at 900 metres above sea level. Large changes in elevation add an orographic component to the type of precipitation occurring in the Nilgiris. This form of precipitation is a result of the mechanical lifting of moist horizontal air currents over vertically elevated natural barriers such as mountains (Viessman, 1995). Water travels through a dense network of tributary streams and rivers in the plateau and drains into two main river systems including the Bhavani to the south, and the Moyar to the north. Accurately estimating the precipitation data is a vital component in developing design specifications for the rainwater harvesting Sub-module 1 and check dam Sub-module 2, which are used to calculate water yields.

Establishing accurate point precipitation data requires a dense network of rain gauge stations that spatially represent the area under study. In addition, the point precipitation data of mountainous regions such as the Nilgiris may be influenced by other factors such as elevation and direction of predominating monsoon winds (Singh, Kumar, 1997). This chapter describes the process for developing precipitation data for 19 rain gauge stations, conducts an analysis of long term trends, and establishes a method for developing point precipitation data.

4.2.1 Data Collection and Database Construction

An important aspect of developing a precipitation database is locating all rain gauge stations within a given area, and deciding which rain gauge stations to integrate into the database. In a country with modest economic resources such as India, accurate data based on sound technical equipment is difficult to find. Every attempt was made in this study to locate precipitation data that reflected the true conditions of the district. Both daily and monthly precipitation data were available for the Nilgiris District. The daily data spanned 23 rain gauge stations over ten years, while the monthly data spanned 12 stations over twenty years.

Heggen (1996) found that rainwater harvesting simulations only caught 10% of the failures when monthly means were used in place of daily data. Therefore, daily precipitation data between 1994 and 2003 were collected for 23 rain gauge stations in the Nilgiris District. After consulting with Myrada, a non-government organization knowledgeable about the hydrological practices of the District, four stations were confirmed unfit for use in developing point precipitation data. The reasons for eliminating rain gauge stations were not based on the inadequacy of the equipment used, but on the ability and discipline of the staff to monitor the station. For example, rain gauge stations at tea plantations were assumed to be rigorously monitored since the trends in precipitation directly affected their livelihood. On the other hand, a rain gauge station at a police station (ie. town of Devala), was assumed not to be the top priority of the monitoring staff. If more time was available for field work, each rain gauge station would have been visited for the purpose of evaluating the equipment and setup. However, for the purpose of this study the assumptions made were adequate. The daily, monthly, and yearly precipitation data for the 19 rain gauge stations are provided in Appendix A, and a number of significant characteristics are presented in Table 10.

Table 10: Precipitation station details and accuracy level

No.	Station	Recorded By:	Annual Rainfall (mm)	CV	%Rainfall	
					SW monsoon	NE monsoon
1	Naicken Shola	Government Tea Estate	1756	0.22	72	19
2	Cherangodu	Government Tea Estate	2210	0.23	70	20
3	Ellamanna	Government Tea Estate	2147	0.21	71	20
4	Nadgani	Forest Department	3536	0.13	76	15
5	Gudular	Revenue Department	1938	0.22	76	15
6	Mudamulai	Indian Institute of Science	1057	0.25	63	19
7	Masinagudi	Indian Institute of Science	732	0.25	47	33
8	Naduvattam	Government Tea Estate	1989	0.17	74	16
9	Glen Morgan	Tamil Nadu Electricity Board	1117	0.22	68	23
10	Outside Ooty	CSWCRTI	1218	0.24	53	29
11	Ootacamund	Meteorological Department	1015	0.19	49	34
12	Kundah Bridge	Tamil Nadu Electricity Board	1220	0.41	35	50
13	Ketti	Railway Station	1483	0.22	37	45
14	Runnemedu	Railway Station	1611	0.22	22	58
15	Hilgrove	Railway Station	1473	0.25	21	56
16	Currency	Private Tea Estate	1612	0.23	21	59
17	Kotagiri	Revenue Department	1372	0.19	28	48
18	Quin Sholai	Government Tea Estate	1504	0.19	26	49
19	Kodanadu	Private Tea Estate	1324	0.26	28	54

CV: coefficient of variation
CSWCRTI: Central soil and water conservation research and training institute

The total area of the Nilgiris District is 2452 km^2, giving the 19 rain gauge stations an average density of one gauge per 136 km^2. This is within the established guidelines set by the World Meteorological Organization for the minimum density of precipitation networks for tropical mountainous regions of 100-250 km^2 (Wilk, 2000). Therefore, the precipitation database has an acceptable network of rain gauge stations to represent the Nilgiris District. The rain gauge stations are not evenly spaced throughout the region, but this ideal situation is difficult to achieve with the current practices of the district. Appendix B, Figures B1 and B2 show maps of the Nilgiris District with and without the 19 marked rain gauge locations.

4.2.2 Statistical Analysis

Statistically analysing precipitation data in the Nilgiris District allows for a better interpretation and understanding of the data. Having only ten years of data for the 19 rain gauge stations makes it difficult to establish the population statistics for precipitation in the region. Since the rain gauge station at the Central Soil and Water Conservation Research and Training Institute (CSWCRTI) had 45 years of monthly precipitation data, this dataset was used to assess the precipitation statistics of the Nilgiris District (Appendix B, Table B1).

A number of key characteristics were developed to understand the statistical variability in the data including:

- Mean (x)
- Variance (s^2)
- Standard Deviation (s)
- Skewness (g)
- Coefficient of Skewness ($C_s = g/s^3$)
- Coefficient of Variation ($C_v = s/x$)

The results of each calculation are displayed in Appendix B, Table B2. From the mean monthly precipitation data, there appears to be a distinct dry period from January to March which receives an average precipitation of 13 mm per month. The occurrence of a dry season impacts the ability of a village to receive an adequate supply of water throughout the entire year. For potential sources such as rooftop rainwater harvesting and check dam structures, a greater storage capacity is required to meet demand. However, one positive aspect of the monthly precipitation data is the two monsoon periods that peak in the months of July and October contributing approximately 978 mm of rainfall. Therefore, the problem that exists in the Nilgiris District is not receiving an adequate supply of water, but creating the mechanisms to store water through man-made structures or recharging the groundwater. The data results are reasonable since the South-West and North-East monsoons extend from June to September and October to December respectively (Wilk, 2000). The SW monsoon contributes to the highest proportion of rainfall for India at 78% (Parthasarathy et al, 1994); however, the state of Tamil Nadu is the only region within India that receives a greater amount from the NE monsoon (Dhar et al., 1982). The SW monsoon is known to have a higher degree of instability and greater vertical depth than the NE monsoon (Dhar, Rakhecka, 1983).

The coefficient of variation is the relative measure of variation about the mean. The values for this coefficient are greater during the months of the dry season, and reach their lowest values in the months of July and October. As a result, the coefficient of variation has a negative correlation with the mean monthly precipitation since the monsoon periods peak in July and October. A similar trend exists for the coefficient of skewness. This is due to a high percentage of zero precipitation values during the dry months. Since precipitation cannot be less than zero, the distribution is positively skewed since the values are not evenly distributed about the mean.

4.2.3 Trends in Precipitation Data

In order to use past precipitation data to forecast future events, it is important to determine if a trend exists within historical data records. Meher-Homji (1984) noticed a significant decrease during 1967-1970 in the Nilgiris District, but stated there was no indication of a large scale shift in precipitation. The length of historical records is an important contributing factor to properly assess the presence of a trend. An observation period of 15-25 years is typically not adequate to develop a stable precipitation distribution, making it necessary to use between 40-50 years of monthly precipitation data (Landsberg, 1951).

Since there were 45 years of monthly data from CSWCRTI, it was assumed the precipitation data time period was acceptable for the purpose of establishing a trend. A linear regression equation was established between the monthly/yearly precipitation data and time to identify trends in the data. The criterion used was a confidence interval of 95 percent which quantified how likely the slope of the regression line was equal to zero, indicating no change in precipitation over time. In other words, if the upper and lower boundary of the 95 percent confidence interval contained zero, it was assumed there was no trend in the data (Vega, Gaona, 1982). As indicated in Table 11 and Appendix B, Figures B3 to B15, the regression equations for yearly and monthly precipitation except June and July contain zero. Since the yearly trend contains zero, this validates the assumption that historical precipitation data can be used to predict future events.

Table 11: Determining Trends in Historical Precipitation Data

MONTH	SLOPE	UPPER CI	LOWER CI	RANGE INCLUDES ZERO
JAN	-0.145	0.142	-0.431	YES
FEB	-0.040	0.304	-0.384	YES
MAR	-0.243	0.387	-0.387	YES
APR	0.236	1.332	-0.860	YES
MAY	-0.717	0.846	-2.280	YES
JUN	2.448	4.340	0.497	NO
JUL	-3.674	-1.020	-6.328	NO
AUG	-0.588	1.225	-2.401	YES
SEP	1.175	2.921	-0.570	YES
OCT	0.646	2.428	-1.136	YES
NOV	0.182	2.514	-2.151	YES
DEC	0.079	1.344	-1.185	YES
YEARLY	-0.640	5.190	-6.470	YES

Another test was performed to determine if the mean yearly precipitation changed significantly over time. The 45 years of precipitation data were separated into nine groups of five for the purpose of conducting an analysis of variance (ANOVA test). The five year intervals started incrementally from 1959 to 2003. To properly run the ANOVA test, it was assumed the populations from the obtained samples followed an approximate normal distribution, the samples were independent, and the variances of the populations were equal. The null hypothesis, H_o, was accepted if the means were the same for each of the nine groups. The alternative hypothesis, H_1, was accepted if at least one of the mean values was different. The theory behind the method was to determine how close the variance between groups (MSB) was to the variance within each group (MSW) (Miller, 1997). If the ratio of MSB to MSW was less than the critical ratio derived from the F-distribution table based on an alpha value of 0.05, the null hypothesis was accepted. Tables B3/B4 and Equations B1/B2 of Appendix B show the data and equations used for developing the ANOVA table, and Table 12 shows the results of the ANOVA test performed on the 45 years of precipitation data at CSWCRTI.

Table 12: Results from ANOVA test on yearly precipitation data

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F_0	$F_{CRITICAL}$
Between Groups	309008	8	38626	0.57	2.21
Within Groups	2420771	36	67244		
Total	2729779	44			

Since the test statistic, F, is less than the critical F, the null hypothesis is accepted. Therefore it is assumed the mean precipitation does not significantly change over time.

4.2.4 Spatial Variability of the Rainfall

The average yearly precipitation in the Nilgiris District is 1734 mm, with a standard deviation of 734 mm, indicating the amount of precipitation varies greatly throughout the district. The coefficient of variation was plotted against the annual precipitation for each rain gauge station (Figure 14) to determine an underlying relationship. It was found that the two have a negative relationship which is a commonly observed pattern (Wilk, 2000).

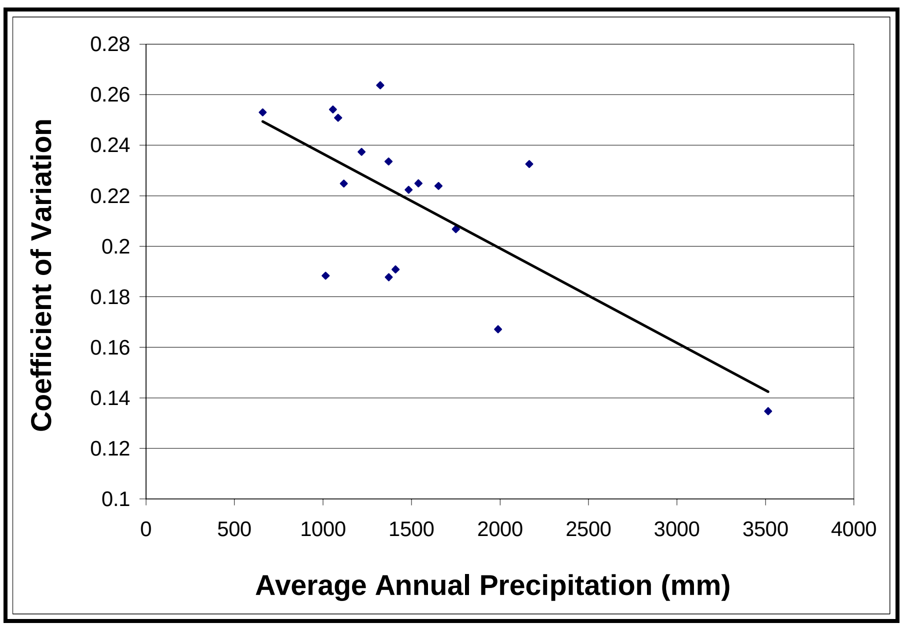

Figure 14: Correlation between coefficient of variation and annual average precipitation

The concept behind developing point precipitation data is weighting rain gauge stations according to their distance from the point location. This method assumes that rain gauge stations within closer proximity are correlated to a greater extent than those farther apart. Therefore, a test was performed to determine if a significant negative relationship existed between station correlations of annual precipitation (R^2), and distance between stations (Figure 15). Appendix B, Table B5 shows the distance between each set of rain gauge stations and Table B6 shows the correlation between the annual precipitation data for each set of rain gauges stations. The results showed a very minor decrease which challenges the validity of using a spatial method for developing point precipitation data.

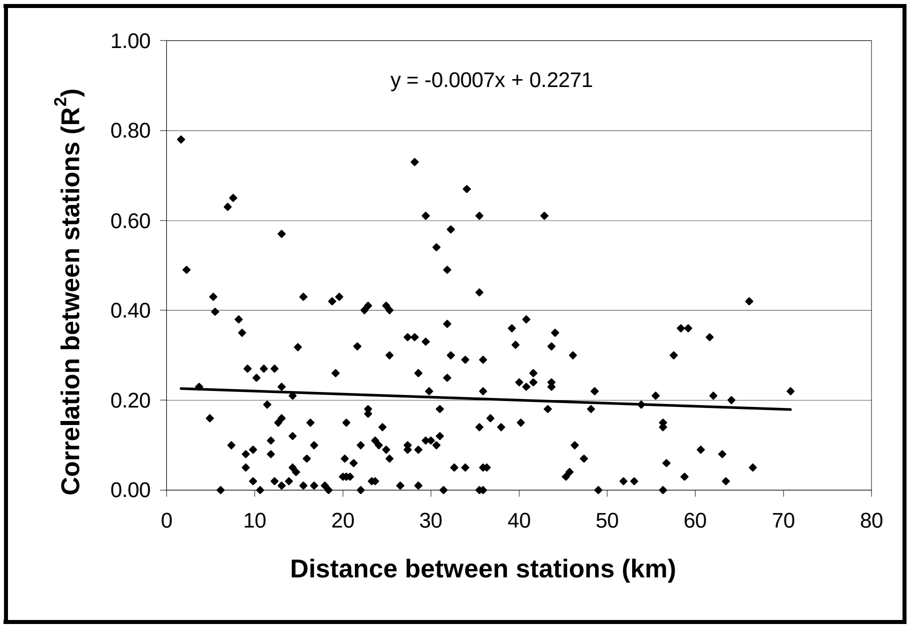

Figure 15: Relationship between correlation and distance for every combination of annual rainfall for the 19 rain stations

The Nilgiris District has two distinct landforms that have significantly different precipitation patterns. The plains at a lower elevation, located in the northern part of the district, are not subject to the orographic form of precipitation caused by mountainous regions. Thus, their rainfall patterns differ from the mountainous region in the south. Subsequently, it has been found that the mountainous region of the Nilgiris District has two distinct land areas that are strongly influenced by opposite monsoon periods (Wilk, 2000). Therefore, in an attempt to improve the procedure for estimating point precipitation data using a weighted method, the rain gauge stations were separated into three areas encompassing the plains, the south-west monsoon dominated mountainous region, and the north-east monsoon dominated mountainous region. By analysing the relationship between station correlation and distance between stations for each of the three regions (Appendix B, Table B16-B18), a great improvement was made over the original test (Table 13).

Table 13: Negative relationship between correlation and station distance between rain gauges

Region	Entire District	Plains	SW Monsoon	NE Monsoon
Rain Gauge Stations	1 to 19	1 to 7	8 to 11	12 to 19
Slope	-0.0007	-0.0082	-0.0193	-0.0087

The negative slopes in all three regions were increased at least twelve fold over the entire district which indicated that using nearby stations to estimate point precipitation data was more accurate with a subdivided district.

4.2.5 Methodology for Developing Point Source Data

The technique used to estimate point precipitation data was a weighting method developed by the Hydrologic Research Laboratory in the United States (Viessman, 1995). For each location, rainfall was estimated by establishing a set of axes running through each point, and taking the weighted average of precipitation at surrounding locations based on distance. The rain gauge station weight was calculated based on its distance from the location developing the point precipitation data. Equations 4-1, 4-2, and 4-3 are used for this method (Viessman, 1995). Using the 19 rain gauge stations in the Nilgiris District, ten years of daily precipitation data were estimated for 95 villages. For rain gauge stations that were missing data for small periods of time, the same method was used to fill in the gaps.

$$PPD = \frac{\sum (P_i * W_i)}{\sum W_i} \tag{4-1}$$

$$W = 1/D^2 \tag{4-2}$$

$$D^2 = \Delta X^2 + \Delta Y^2 \tag{4-3}$$

where,

PPD = point precipitation data at specific location
P_i: = rainfall data at nearby rain gauge station i
W_i = weight of rain gauge station i
D = distance from location to rain gauge station

The selection process for choosing rain gauge stations was based on the village's location within one of the three regions encompassing the plains, the south-west monsoon dominated mountainous region, and the north-east monsoon dominated mountainous region. Since the two monsoon periods had varying degrees of influence over different regions of the Nilgiris District, it was essential to target specific stations when developing point source data. In other words, only stations lying within the same monsoon influenced region were used to develop precipitation. A study carried out by Wilk & Andersson (2000), divided the Nilgiris District into regions based on whether the physical characteristics were similar to rainfall stations in the SW-group or the NE-group. Figure 16 shows the results of the study which also included a black region for areas that were unclassified. The villages located in the black region were assumed to be evenly influenced by both monsoons. Thus, rain gauge stations located in both the south-west monsoon dominated region and the north-east monsoon dominated region were used in this case. Appendix B, Tables B7 and B8 shows the equation variables for each village.

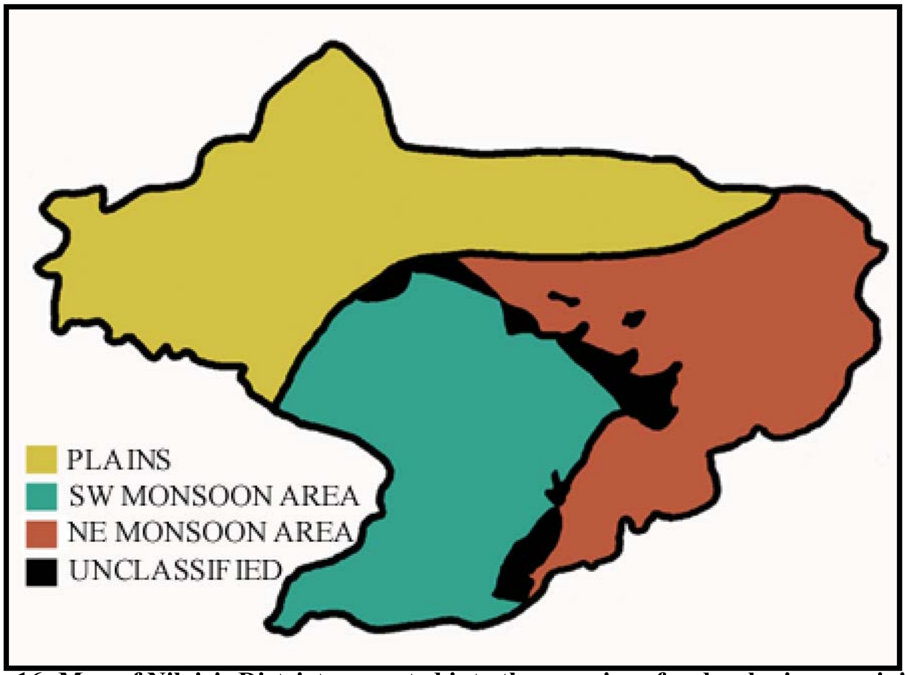

Figure 16: Map of Nilgiris District separated into three regions for developing precipitation

4.3 CHECK DAM MODEL

Estimating hydrological data and running a check dam simulation is difficult in a region that has limited data. Since the accuracy of a model depends on the quality of input variables, a suitable model should be selected based on the available data. When only rainfall and runoff data are available, it is difficult to justify extensive conceptualisation of complex hydrological processes (Jakeman, Hornberger, 1993). Four potential methods for establishing streamflow in the check dam Sub-module 2 are described in order of decreasing complexity:

- IHACRES model using regionalisation technique;
- Pitman model;
- IHACRES using disaggregation technique;
- Dry season baseflow.

4.3.1 Method 1: IHACRES Model Using Regionalisation Technique

The complexity of a rainfall-runoff model is related to the number of parameters being used. If a rainfall-runoff model is being implemented in a region with little hydrological data, an appropriate low-parameter model should be chosen that accurately represents the characteristics of the watershed (Kokkonen, Jakeman, 2001). For simulating streamflow, accurate precipitation data is often more important than the choice of complexity of the hydrological model (Gan et al, 1997). IHACRES is a relatively simple six parameter conceptual rainfall-runoff model that requires daily precipitation and temperature data as input variables. Conceptual rainfall-runoff models describe the components of the hydrological cycle perceived to be of importance as simplified conceptualisations. The components are laid out in a system of interconnected units that are recharged and depleted by different components of the hydrological cycle.

The IHACRES model which predicts a daily flow time series has been used in numerous studies (Kokkonen et al, 2003; Post, Jakeman, 1999; Sefton, Howarth, 1998) that use regionalisation techniques to transfer information from gauged to ungauged catchments. The model consists of two modules; a non-linear module that converts rainfall to effective rainfall and rainfall excess, and a linear transformation module that converts effective rainfall to streamflow (Figure 17).

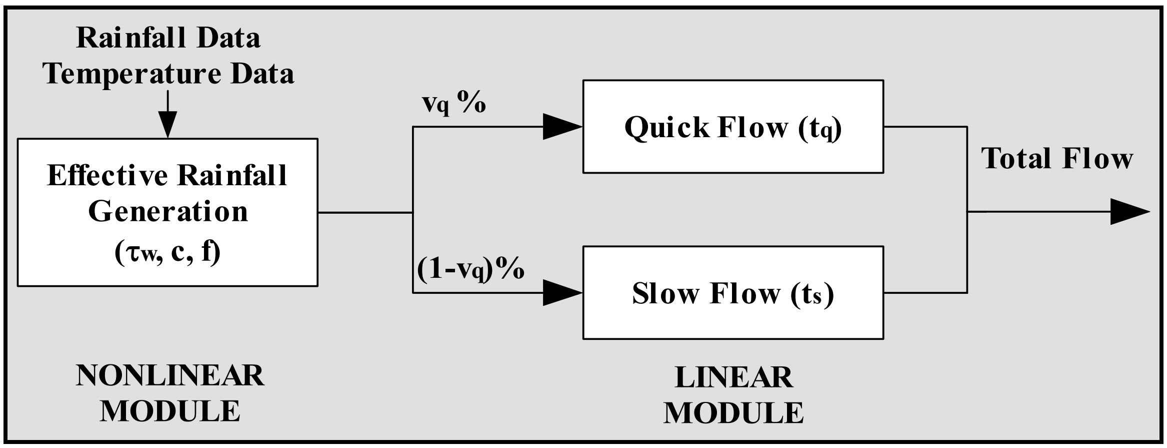

Figure 17: Schematic representation of the IHACRES rainfall-runoff model

Thus, all water losses occur in the non-linear module (Post, Jakeman, 1999). The linear module has two units for quick and slow flows which combine to make up the total streamflow. The quick flow is representative of the runoff and direct precipitation that enters the stream soon after a rainfall. The slow flow is representative of the water that travels at a slower speed through the ground, eventually making its way to a stream system. There are six parameters in the IHACRES model as described below (Kokkonen et el, 2003):

- τw: time constant governing the rate of water loss from the catchment at 20 degrees Celsius;
- c: inversely represents the increase in storage index per unit rainfall in the absence of evapotranspiration;
- f: temperature modulation parameter on the rate of evapotranspiration;
- vq: the partitioning coefficient between the two stores;
- tq: time constant governing the rate of recession in the quicker of the two parallel units;
- ts: time constant governing the rate of recession in the slower of the two stores.

Since the catchments being used for the check dam model are small and ungauged, it is difficult to establish site specific streamflow data. A technique used to model ungauged catchments based on gauged catchments with similar hydrological characteristics is called regionalisation (Bloschl, Sivapalan, 1995). The assumption is that catchments behave similar to other catchments under similar climatic conditions and landscape attributes. As such, if a large number of IHACRES models are calibrated, a relationship can be found between the physical attributes and model parameters for the purpose of transferring information to ungauged catchments. It is not sufficient to use mean calibrated parameters as a regionalisation technique. Since the physical properties of catchments are different, a regression-based technique of finding a correlation between runoff model parameters is more accurate (Kokkonen et al, 2003).

Five critical criteria for successful regionalisation of rainfall-runoff model parameters are outlined by Kokkonen et al (2003) including: accurate estimation of parameters at gauged stations; selection of physical catchment descriptors that accurately depict the catchment response to rainfall; delineation of homogeneous regions; extent of correlation between model parameters and catchment characteristics; and an appropriate model used for each region. The greatest challenge in applying regionalisation techniques is defining suitable homogeneous regions (Potter, 1987).

One key aspect of successful regionalisation is choosing physical catchment descriptors that are highly correlated with the model parameters. Many different physical catchment descriptors have been identified as significant drivers in developing regression equations with the parameters of the IHACRES model including:

- Elevation, slope, mean overland flow distance to a stream (Kokkonen et al, 2003).
- Area, Drainage Density, Elongation, Gradient, Slope, Wetted Area (Post, Jakeman, 1999)
- Land cover, soil variables, climatic variables, topography (Sefton, Howarth, 1998)

4.3.2 Method 2: Pitman Model

A study has previously been carried out to simulate streamflow in the Nilgiris District using the Pitman conceptual rainfall-runoff model (Wilk, 2002). Four models were calibrated at gauged streamflow stations which encompass the entire District catchment area. The District has a complex system of reservoirs and hydro-electric power generators that make it difficult to establish the natural flow rates. This problem is compounded by the lack of information regarding the release of water from the reservoirs. These factors were taken into consideration when developing the rainfall-runoff models.

The Pitman model is suitable for the Nilgiris District since it has minimal data requirements and has been used in a wide variety of catchment types and climatic conditions across South Africa (Wilk, 2002). The model inputs include monthly precipitation and mean monthly potential evapotranspiration. The version of the Pitman model applied to the Nilgiris District is a slight variation from the original model as described in Hughes (1995). The main parameters in the Pitman model are outlined in Table 14.

Table 14: Definition of main Pitman model parameters

Parameter	Units	Description
PIV, PIF	Mm	Interception storage parameters for natural grassland and for forest cover
AI	%	Impervious part of the sub-catchment
Z:		Three parameters defining the asymmetric triangular frequency distribution of catchment absorption rates:
ZMIN	mm/month	Minimum
ZAVE	mm/month	Average
ZMAX	mm/month	Maximum
ST	Mm	Maximum moisture storage capacity
FT	mm/month	Runoff from moisture storage at full capacity (ST)
FF		Ratio of forest/grassland potential evapotranspiration
R		Evaporation-moisture storage relationship parameter
POW		Power of the (runoff-soil moisture) curve

Source: Wilk (2002)

The Pitman model is a lumped conceptual model that is typically applied to larger catchment areas. For this method to be used on smaller catchments, the calibrated parameters would require a method to transfer the information to ungauged catchments. One advantage of this method is the model has already been calibrated for the Nilgiris District.

4.3.3 Method 3: IHACRES Using Disaggregation Technique

Assuming the streamflow from any sub-catchment within a larger catchment is proportional to the ratio of the catchment's area and average slope, the streamflow at an ungauged station can be simulated using a disaggregation technique (Schreider et al, 2000). The disaggregation technique transfers information from a larger catchment that has been calibrated using a rainfall-runoff model, to an ungauged catchment within. This is accomplished through a semi-distributed modelling scheme known as TOPMODEL which sub-divides a catchment area and utilises topography to estimate the extent of streamflow contribution within a larger catchment (Beven, Kirby, 1979). Equation 4-4 is used in TOPMODEL to develop topographical indices for different sub-catchment areas (Beven et al, 1984).

$$\omega_j = \ln\left[\frac{A_j}{l_j \tan(\phi_j)}\right] \qquad (4\text{-}4)$$

where,
- j = the number of cells in the catchment area
- ω = topographic index
- A = drainage area above grid cell
- l = width of the contour of the grid cell
- Φ = average slope of the grid cell

Schreider et al (2000) uses a simplified topographical index method to scale the volumetric parameter, c, in the non-linear module of the IHACRES model (refer to section 4.3.1) to estimate streamflow at the ungauged location. The parameter is scaled using Equation 4-5.

$$C\frac{a}{\tan(\phi)} = c\frac{A}{\tan(\Phi)} \qquad (4\text{-}5)$$

The upper case letters represent the physical characteristics of the entire catchment, whereas the lower case letters represent those for the sub-catchment. As such, the streamflow is simulated for the ungauged catchment using the same calibrated parameters for the larger catchment, while only changing the volumetric parameter based on the difference in topographical index. One limitation of this method is the scaling being restricted to the non-linear module and not being incorporated into the linear quick and slow flow units (Schreider et al, 2000).

4.3.4 Method 4: Dry Season Baseflow

There are four principal components that constitute streamflow; direct surface runoff, interflow, channel precipitation, and baseflow. During the initial stages of precipitation, the void spaces in the ground allow water to travel underground, creating a storage capacity that maintains the rivers during the dry season. A small portion of the water travelling underground, known as interflow, does not reach the water table level and travels directly to the stream. As soon as the physical properties of the ground do not permit additional flow of water, the excess water travels as direct surface runoff above ground along the path of least resistance towards a stream. Lastly, precipitation that falls directly into the stream is termed, channel precipitation.

The Nilgiris District is influenced by two monsoon periods which bring extensive quantities of rainfall, and a dry season which brings very little precipitation. Since there is little or no precipitation during the dry season, the only principal component contributing to streamflow is baseflow. It is during this critical time period that the flow of perennial streams decreases, and the flow of non-perennial streams completely dry up making it difficult for a village to obtain an adequate supply of water. Every method developed in this chapter has analysed the streamflow throughout the entire year. These methods put a great deal of effort into developing streamflow data during times when water is plentiful. By conducting a survey with ten villages that use check dams for domestic water supply, it was found that the only time the village received less water than their ideal demand was during three to four months of the dry season. The premise behind the 'Dry Season Baseflow' method is to analyse the critical dry season period for determining storage requirements.

The area of study relating to the rate at which groundwater is released into a stream without recharge from precipitation was one of the earliest fields of investigation in hydrology (Nathan, McMahon, 1990). It was found that a recession constant exists in the form (Viessman, Lewis, 1995):

$$q_t = q_o e^{Kt} \tag{4-6}$$

where,

q_o = a specified initial discharge
q_t = the discharge at anytime t after flow q_o
K = a recession constant
e = base of natural logarithms

Recessions that follow Equation 4-6, plot as a straight line on semi-logarithmic graphs where the slope is equal to the recession constant. In order to establish a recession constant, site-specific streamflow is required at equal time intervals. It is difficult to accomplish this task when rainfall is distributed evenly throughout the year, but since the Nilgiris District has a distinct dry season, a simple v-notch apparatus can be installed to take daily streamflow readings. For most watersheds, groundwater release characteristics are approximately stable, since they are closely related to the physical characteristics of the soil which do not change greatly over time (Viessman, Lewis, 1995). Therefore, if a reasonable initial discharge rate is provided by the user, the simulated streamflow can be an effective tool for estimating storage requirements for a significant period of time. One negative aspect of this method is the inability to compare simulated and observed streamflow for calibration purposes. Additionally, Sujono et al (2004) suggests that problems arise in using a semi-logarithmic plot when the data produce a curved line as opposed to an expected linear relationship. The curved line is typically the result of the transition between the end of direct flow and the beginning of baseflow (Sujono et al, 2004). Since the streams being used for check dam construction in the Nilgiris are small and not perennial, the transition between the two phases is easier to observe.

4.3.5 Method Selection

The four streamflow models considered for use within the check dam simulation range in complexity from lumped conceptual rainfall-runoff models to isolating the critical dry season of the year. The criteria used to compare the methods are presented in the following list.

- data requirements
- time requirements
- cost
- accuracy

An evaluation of the criteria for each method are described in the following paragraphs and summarised in Table 15.

Table 15: Evaluation of criteria for each streamflow method

METHOD #	DATA REQUIREMENTS	TIME REQUIREMENTS	COST	ACCURACY
1	High	High	High	High
2	High	High	High	Low
3	Medium	Medium	Medium	Medium
4	**Low**	**Medium**	**Low**	**Medium**

Method 1: Regionalisation techniques can be used to simulate streamflow at ungauged locations for small catchments, but a large number of calibrated IHACRES models are required to determine regression equations. The average number of catchments used for three studies was 30 (Kokkonen et al, 2003; Post, Jakeman, 1999; Sefton, Howarth, 1998). Currently there is not enough data to support such models and would require substantial funds to do so. However, if this technique could be implemented it would have a high degree of accuracy since small catchments could be modelled, limiting the effects of artificial flows from the reservoirs and transfer tunnels located in the District.

Method 2: The Pitman model is a lumped conceptual rainfall-runoff model ideal for larger catchments. Since the Pitman model uses a large number of parameters, applying the model to small catchments less than 100 hectares would not be a sensible use of funds and would be time consuming. Even though this model has been calibrated for large catchments in the Nilgiris District, it would be difficult to transfer information to smaller catchments. As well, with limited data it is difficult to justify substantial conceptualisation of complex hydrological processes (Kokkonen, Jakeman, 2001).

Method 3: As opposed to 'Method 1' which requires the IHACRES model calibration of many catchments, this method requires one. Since the ungauged catchment being estimated must lie within a larger catchment area, only targeted regions in the Nilgiris District could be developed. On the other hand, if larger catchment areas are considered, separating artificial and natural flows caused by the extensive network of reservoirs and transfer tunnels for hydropower purposes becomes necessary. A study found that the relative errors for the monthly streamflow of two ungauged sub-catchments using this method were 13 and 17 percent (Schreider el al, 2000).

Method 4: Establishing streamflow using only the dry season baseflow is a simplified method, but effective since it isolates the critical period during the year where flow is at a minimum. The data requirements of daily streamflow for one dry season are minimal, requiring little time to gather. The only costs involved are setting up a v-notch apparatus to measure flow through the stream.

By comparing the criteria for each method and quantifying them on Table 15, it is clearly demonstrated that the dry season baseflow Method 4 is most suitable for the conditions of the Nilgiris District.

4.4 Module 1: Water Source Yield

The first module in the NRWS develops the potential water source yield for every source being considered in the respective village. Arguably this is the most important criterion to develop because there is little flexibility in altering water source yield after implementation, whereas problems arising from the other criteria can be resolved with adequate funding. The sources of water commonly used in the Nilgiris District were described in Chapter 3. From the main menu of NRWS, Module 1 can be accessed by clicking on the respective hyperlink which is clearly specified on the worksheet. Once entered into Module 1, there are three components that must be completed including: village water demand; estimating water source yield; and assigning scores for the source yield criterion.

Since Module 1 is the most technically intensive module and requires widespread input and interaction from the user, the potential water sources are divided into sub-modules. Thus, the following six sections describe the user input, computer processes, computer output, and assumptions/simplifications for the 'Water Source Yield' module along with each of the five sub-modules representing each potential source.

The sub-modules of Module 1 use different methodologies to develop the potential yields of the five available water sources. Varying degrees of complexity and output variables make it necessary to create a generic template for comparison purposes. Presented in the format of a table, the template is located on the Module 1 worksheet and shows the yearly and monthly percent reliabilities of each source.

4.4.1 General Module

4.4.1.1 User Input

There are two components on the main worksheet for Module 1 that require user input including the village water demand, and assigning scores for the source yield criterion. Developing the water demand for a village requires a process that incorporates the opinions and ideas from every member of the village. Effective communication is vital between stakeholders if demand is to be met (Deverill et al, 2002). Evidence supports the idea that the misjudgement of planners developing water demand is an important contributing factor to the failure of water projects in developing countries (Parry-Jones, 1999). Within the NRWS program, the user inputs a daily water demand for every month of the year to account for seasonal variations in demand. As well, the user must input the total number of people in the village to form the total daily village water demand. Another option is entering daily demand on a per family basis in cases where an individual rate does not accurately depict the true conditions of the village.

If the village being assessed has existing water supplies that will continue after the new source is implemented, a link is activated by the user to input the current monthly water supplies from these sources (Figure 18). Furthermore, if the village is to use the water source only for drinking purposes, a significantly lower demand is required. The purpose of the potential water source should be clearly developed by the project stakeholders. All the above conditions for assessing water demand are described to the user in a help file (Appendix F, Section 1).

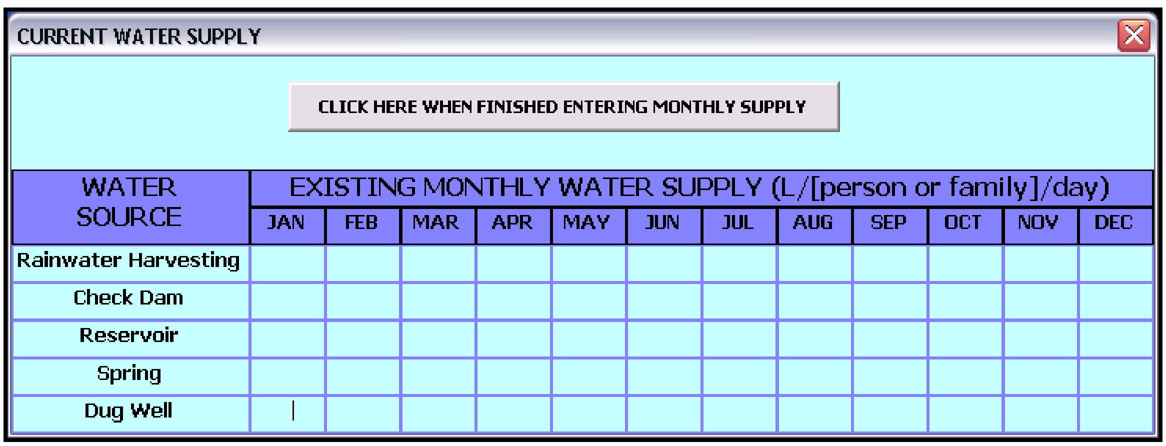

Figure 18: User form for inputting existing water supply values

The last component of Module 1 requires the user to assess the importance of the water source yield criterion to the village, and to evaluate the effectiveness of each source with respect to providing an adequate water supply. This is accomplished through a weighting and scoring system which prompts the user to input a number between zero and ten for both the criterion weight and the water source scores. A higher score is assigned to water sources that are able to meet the demands of the village. House and Reed (1997) have developed a guideline table for helping the user decide appropriate water source scores for this criterion. The table is displayed in Module 1 to assist the user.

4.4.1.2 Computer Processes and Outputs

As mentioned at the being of section 4.4, there are three components in Module 1 including water demand, estimating source yields, and assigning weights and scores. A network of hyperlinks allows the user to switch between the three components or return to the main menu. Establishing the village water demand is essential for estimating the potential yields from each source since the basis for determining supply depends heavily on the quantity of water required by the village. More importantly, the water demand is essential in the equations and algorithms used for estimating source yield. As a result, the hyperlinks that allow users to estimate source yields cannot be accessed until the demand component is complete. The last component of the module uses the information developed in the first two components to help assign a score for the potential sources based on their ability to provide an acceptable yield.

Within the Module 1 worksheet there are no data classified as output; however, the sub-modules provide an extensive amount of output that is useful to the user in deciding water source scores and additional design parameters. A standardized output table displays the overall and monthly percent reliabilities for each of the potential water sources for comparison purposes. This allows the user to judge the effectiveness of each source in supplying water to the village throughout different seasons of the year. Once the user has assigned a weight for the criterion and a score for each potential source, this information is transferred to the decision matrix which is accessible to the user only after completing all six modules.

4.4.1.3 Assumptions and Simplifications

Estimating water demand for a village is crucial in identifying appropriate sources to implement. However, an in-depth analysis is difficult to attain without making a number of assumptions and simplifications. Demand calculations should take into consideration the number of users to be served, the anticipated population growth rate over the infrastructure lifespan, and seasonal demand variations (Deverill et al, 2002). It is assumed that the average lifespan of a water supply infrastructure is twenty years, based on data from the Nilgiris District. The population growth rate is the only factor not directly incorporated into the algorithms of NRWS due to the current population trends in the Nilgiris District. Population statistics from the Office of the Registrar General (2001) are described in Tables 16 and 17.

Table 16: Decadal population growth in the Nilgiris District over 30 years

Time Period	Decadal Population Growth (%)
1971-1981	27.6
1981-1991	12.7
1991-2001	7.7

Table 17: Percentage of rural and urban populations in the Nilgiris District

Year	Rural Population (%)	Urban Population (%)
1991	50.2	49.8
2001	40.5	59.5

The population trends indicate the growth rate across the district is decreasing, and the percentage of people living in rural areas is also decreasing. Therefore an assumption is made that the population growth rate for villages in the Nilgiris District is not significant enough to warrant including a factor in the calculation. However, if the user believes the growth rate is a significant factor for a specific village, an adjustment to the number of people in the village can be carried out by the user. Lastly, the water demand developed in NRWS assumes a rationing technique where users consume a consistent supply of water based on an established monthly demand (Pacey, Cullis, 1986). This assumption is unrealistic as it is difficult to strictly monitor water consumption, but it is the best approach for the purpose of establishing an estimate.

4.4.2 Sub-module 1: Rainwater Harvesting

4.4.2.1 User Input

NRWS uses a daily simulation over ten years for estimating source yield from a rooftop rainwater harvesting system. The user has three different options in running the simulation as described in the following points.

OPTION #1- finding the system's percent reliability based on a known storage capacity
OPTION #2- finding the ideal storage requirements based on a required percent reliability
OPTION #3- developing a graph of storage requirement versus percent reliability

Figure 19 shows the user form created in VBA for gathering information relating to Option #1. The user forms for the other two options are similar in appearance but prompt the user for slightly different input.

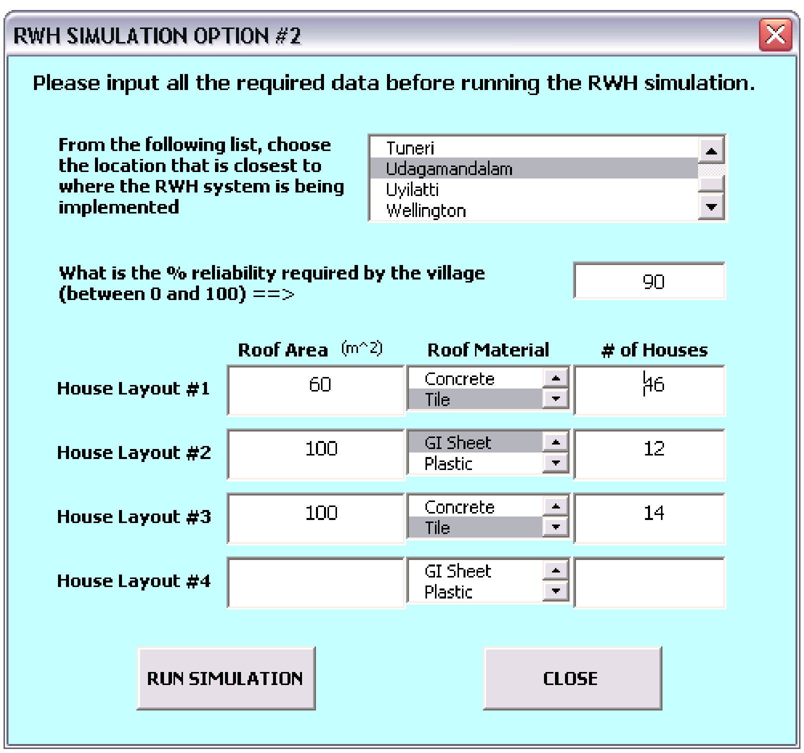

Figure 19: UserForm in NRWS for Option #1 of RWH simulation

The first two options are applied when the user has specific requirements for percent reliability as requested by the village, or the maximum storage capacity based on the spatial availability and economic conditions of the village. Otherwise, the user can choose to create a graph that compares the two variables in order to determine a balance that maximises their effectiveness. If the graphing option is selected, the user must still run through one of the first two options in order to obtain the necessary output values for the sub-module. The input variables for all three options are similar but vary with respect to percent reliability and storage capacity as shown in Table 18.

Table 18: Input requirements for RWH simulation options

INPUT VARIABLE	OPTION 1	OPTION 2	OPTION 3
Percent Reliability		x	
Storage Capacity	x		
Village Location	x	x	x
Catchment Area	x	x	x
Rooftop Material	x	x	x
Quantity of House Type	x	x	x

The effectiveness of the simulation depends on the quality of information provided by the user. As such, each variable should be carefully developed to represent the true conditions of the village and viewpoints of the villagers. The first input variable to appear on the form prompts the user to choose from a list of 95 locations to establish site-specific precipitation data. The location is chosen based on its proximity to the application village. An area within a six kilometre radius of each location encompasses the entire Nilgiris District, providing an acceptable spatial distribution. Next, depending on the simulation option, the user inputs the percent reliability and storage capacity. These are complex variables to develop since they require qualitative characteristics that reflect villager perception. However, they are easier to understand after completing simulation option three which graphically illustrates their relationship.

The final set of user input variables are catchment area, rooftop material, and quantity of house type, which outline the rooftop characteristics of buildings being used to capture rainfall. They are set up in a table which allows the user to enter a maximum of four house types which combine to calculate the total effective catchment area transferring water to a storage unit. The rooftop materials are presented in a list which translates into the runoff coefficients used to calculate the percentage of rainfall being utilised. The runoff coefficients used in the simulation are based on a number of different references as described in Table 19.

Table 19: Runoff coefficients used in simulation

ROOFTOP MATERIAL	Sahu (2002)	Pacey (1986)	Gould (1999)	Values used for Thesis
GI Sheet	0.9	0.9	0.85	**0.9**
Plastic	-	0.8	-	**0.8**
Concrete	0.7	-	-	**0.7**
Tile	0.75	0.9	0.39	**0.6**

Since the tiled rooftop material shows variation across the available references, an average of the two most recent references is used to calculated percent runoff, assuming the coefficient developed in Pacey (1986) is not valid.

4.4.2.2 Computer Processes

Once the user has entered all necessary input variables corresponding to the respective option, a sequence of algorithms is initiated to run the simulation. There are few differences in the computer code for developing the algorithms of each option since they generally follow Equations 4-7 to 4-9 (Heggen, 1996).

$$C_i = \min\begin{cases} S_{i-1} + AP_i z \\ D_i \end{cases} \quad (4\text{-}7)$$

$$Q_i = \max\begin{cases} S_{i-1} + AP_i z - V - C_i \\ 0 \end{cases} \quad (4\text{-}8)$$

$$S_i = S_{i-1} + AP_i z - Q_i - C_i \quad (4\text{-}9)$$

where,

A	= catchment area (m^2)	S_i	= storage at the end of period i (L)
C_i	= consumption in period i (L)	Q_i	= spill in period i (L)
D_i	= target water demand for period i (L/day)	V	= storage capacity (L)
P_i	= rainfall over given time period (mm)	z	= runoff coefficient

A number of different methods for developing design specifications of rainwater harvesting units were compared in Appendix D. The simulation method was found to provide the most robust results based on the available hydrological data in the region. The equations take into consideration all the potential inflows and outflows to the storage unit on a daily basis to determine if an adequate village water demand is met. The computer processes used to develop the general algorithms for Simulation Option 1 are illustrated in Figure 20. All three simulation options share similar computer processes; however, there are differences that make each option unique. One key difference between the first two options is the number of simulations that must be run to obtain the required output. The first option determines the percent reliability based on a given storage capacity. Only one simulation is necessary since the equations being used directly solve for percent reliability. The second option oppositely determines an ideal storage capacity based on a given percent reliability. Since the equations solve for percent reliability, a storage capacity must be estimated based on reasonable assumptions. If the storage capacity does not meet the required percent reliability on the first simulation, it is incrementally increased or decreased until the conditions are satisfied. The reliability is calculated based on the total number of run failures, which occur when the actual village consumption is less than two-thirds the village demand. The third option uses the same computer processes as the second, but performs them at numerous percent reliability values in order to create a chart that shows the relationship between storage capacity and percent reliability.

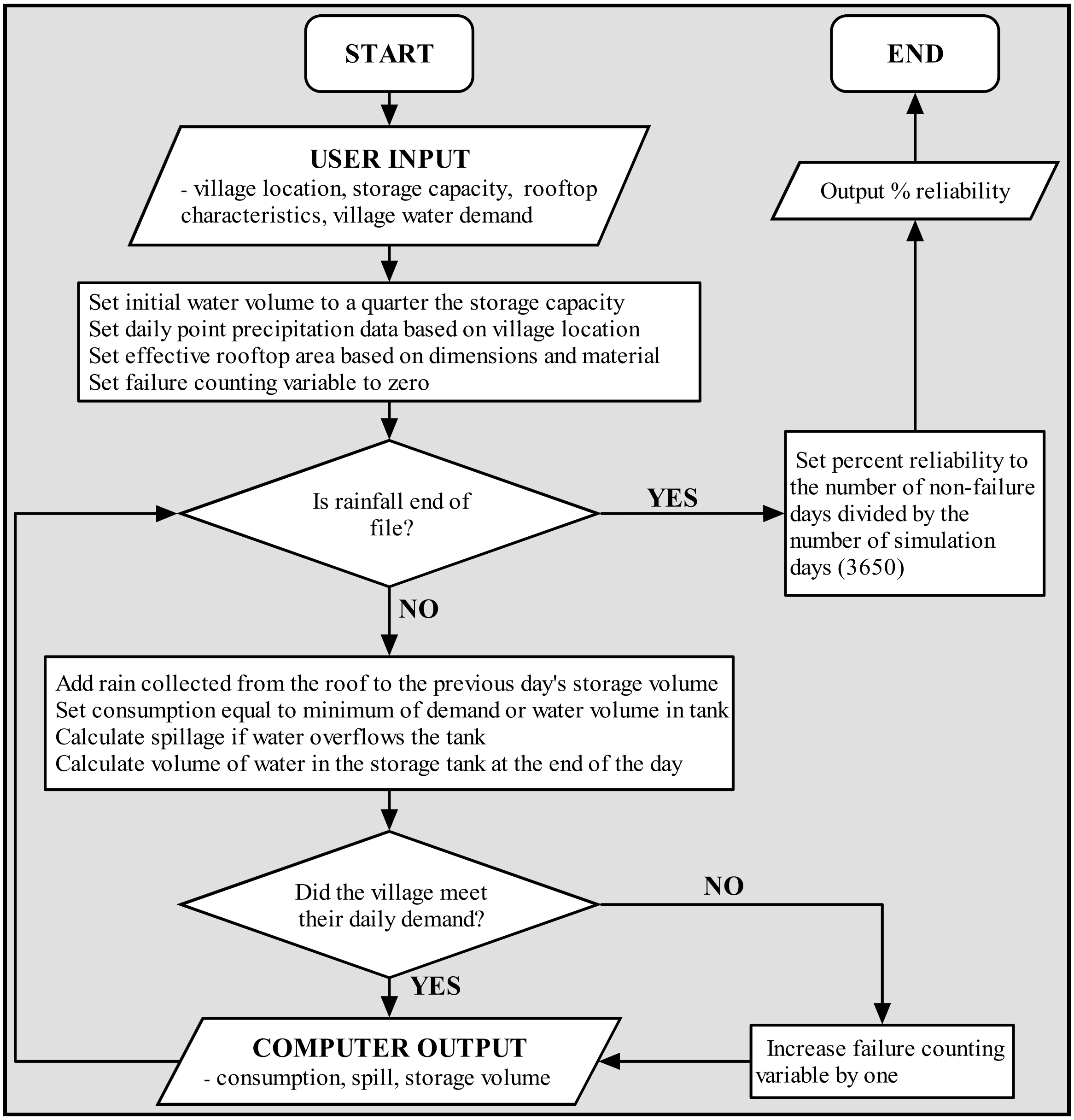

Figure 20: Flow chart describing the basic rainwater harvesting simulation model

4.4.2.3 Computer Output

The purpose of the rainwater harvesting simulation within the context of Module 1 is to determine the overall and monthly percent reliability levels to compare with other potential sources. However, there are three options for running the rainwater harvesting simulation resulting in three different sets of output. To standardise the transfer of information from the RWH sub-module to Module 1, a uniform template is used to summarise the inputs and outputs from the first two simulation options which includes: village location; number of houses in village; total rooftop area; village storage requirements; average household storage requirements; overall percent reliability; and monthly percent reliability. The third option is specified as a guideline to help effectively run the first two options. Most of the data on the uniform template allows the user to assess potential input adjustments if the results of the simulation are not satisfactory.

Output for Simulation Option 3 is a graphical illustration outlining the relationship between village storage requirement and percent reliability. The graph alone cannot be used to develop the overall output for the RWH sub-module. However, it can be used to help the user find an appropriate balance between storage and reliability in order to run one of the first two simulation options. Unknown storage requirements are calculated for reliability levels of 50, 60, 70, 80, 85, 90, 95, and 100 percent. It is suggested to the user to analyse the rate of increase of storage over the reliability intervals. If there is a gradual increase throughout the graph, the user may be prone to choosing a higher reliability level since the additional cost of increasing storage is manageable. Conversely, if there is a point in the graph where the storage requirements suddenly increase exponentially, the user may not be willing to fund the storage requirements for a higher reliability level. This concept is better understood through Figure 21 which shows the results of an example simulation run. The change in storage requirements over a ten percent increase relating to the 70, 80, and 90 percent reliability levels are approximately 20, 40, and 80 m^3 respectively, a factor of two for each subsequent increase. The user must then gauge the feasibility of doubling the storage requirements based on a reliability increase of only ten percent. As well, from 90-95 percent reliability the storage capacity increases by 20 m^3, whereas the jump from 95-100 percent is approximately 60 m^3. These illustrations will help the user determine the feasibility of different storage requirements.

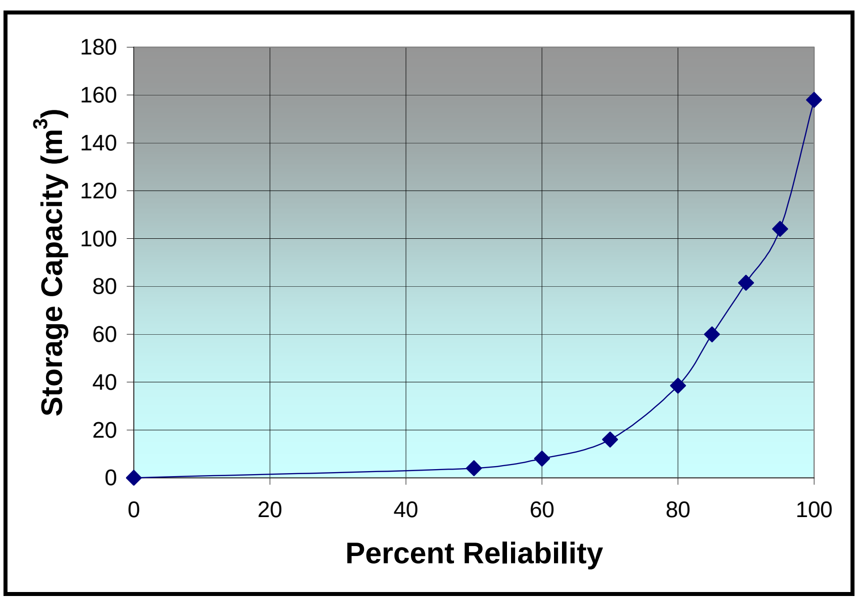

Figure 21: Output for simulation option 3 showing relationship between reliability and storage

4.4.2.4 Assumptions and Simplifications

The assumptions and simplifications for the rainwater harvesting simulation options are carefully developed to ensure maximum model effectiveness based on available resources. Throughout this section, the assumptions and simplifications are described within three topics: user input, computer processes, and computer output.

The first input variable required from the user is selecting a village location for developing rainfall data. Since point precipitation data were developed for only 95 villages across the district, it is possible that the village being assessed is not listed. As a result, rainfall at the application village is assumed to be equal to rainfall at the nearest location provided by NRWS. There were two factors taken into consideration for selecting the locations for point precipitation data including: simplifying the user choice by limiting the number to fewer than 100; and maintaining an even distribution across the district. The maximum possible distance from an application village to a location with point precipitation data is six kilometres which is accepted as a reasonable distance. The second assumption made with respect to user input is that the total water demand over the ten year simulation period must be less than the total water supply. If this condition is not met, the simulation stops and the user is prompted to either increase the rooftop area or decrease the monthly water demand. This assumption is important because it ensures the RWH system is able to perform at 100% reliability. The mass balance approach to developing storage requirements uses the same assumption (Gould and Nissen-Petersen, 1999).

There are two potential methods for running a rainwater harvesting simulation. 'Consumption before spill' uses the assumption that the demand is met before spillage occurs. 'Spill before consumption' is the opposite where spillage precedes the demand being met for each simulation run. The technique best suited for NRWS is 'consumption before spill' since it allows for a greater chance at achieving the ideal demand. For this assumption to hold true, the traditional twelve litre storage containers called 'koodhams' which are used in most rural households in the district should be filled early in the day to maximise efficiency of the storage unit. Two other assumptions consistent across all three simulation options include: the RWH systems are constructed during the dry season to be ready for April 1st; and the tank is a quarter full at the beginning of the simulation. The basis of the first assumption is to ensure the dry season months between January and March do not impede the RWH systems ability to obtain 100% reliability during the first year. As well, to further ensure the beginning of the simulation is not susceptible to rare drought occurrences in April, the storage unit is given an initial volume of a quarter the storage capacity. Simulation options two and three require an additional assumption to estimate an initial storage capacity for the first simulation run. The equation used is:

$$Storage = Demand \times \%reliability \times 75days \tag{4-10}$$

As shown in Equation 4-10, the calculation for estimating initial storage capacity uses a demand side approach. If the user requires a 100% reliability level, the storage capacity must be at least the volume of water demanded by the village during a typical dry period. Since the average dry period is between two and a half to three months based on the generated precipitation data, a period of 75 days is used. An adjustment factor reduces the water demand of the dry period based on the percent reliability inputted by the user. The only benefit to accurately estimating storage capacity is to minimize the number of simulations needed to determine the ideal value.

The simulation output is simplified since the storage requirements are presented as an average per house as opposed to details specific to each house type. Realistically, households with greater economic wealth have larger houses resulting in a greater effective rooftop area for capturing water. As well, households have varying numbers of people resulting in different water demands per house. Consequently, the stand-alone software version of the rainwater harvesting simulation model should be used to estimate storage requirements on a household basis. The total village storage requirements are useful in generating an estimated total cost for implementing a village-wide RWH system.

For simulation option three, the range of values for percent reliability are between 50 to 100 percent to develop a relationship between storage requirements and reliability. Since the computers being used in India for NRWS do not have advanced processing chips, the number of simulations should be minimized to allow for quicker results. It is assumed that villages will not develop a RWH system to supply water to the villagers for less than half the days of the year. As shown in Figure 21, the critical changes in storage requirements occur at higher percent reliability values thus making it necessary to have smaller increments at higher values.

4.4.3 Sub-module 2: Check Dam

4.4.3.1 User Input

Since the fundamental principles used to develop the check dam simulation are similar to the rainwater harvesting simulation, the same three options in sub-module 1 are provided to the user in sub-module 2. However, the check dam simulation involves a more complex network of input data requiring resources to conduct field work. The complete list of user input for each simulation option is provided in Table 20.

Table 20: Input requirements for RWH simulation options

INPUT VARIABLE	OPTION 1	OPTION 2	OPTION 3
Percent reliability		x	
Combined reservoir and tank capacity	x		
Check dam location	x	x	x
Tank storage capacity	x	x	x
Initial stream discharge	x	x	x
Streamflow data for recession constant	x	x	x
Ratio of reservoir surface area to depth	x	x	x

In the Nilgiris District, water stored in a check dam reservoir is gravity-fed through a pipeline to a water tank located above the village for distribution purposes. The storage capacity of the reservoir and water tank is considered one unit since the two systems are connected by a pipeline. Thus, for Option #1 the user is required to enter an estimate of the total storage capacity available to the village. In addition, it is important to determine the storage capacity of each unit separately since water loss variables such as evaporation only occur in the open reservoir. Consequently, the user must input the size of the water tank being used to store water. Currently within the Nilgiris District, this size varies depending on the village population but averages 5 m^3 for every 100 people.

Unlike the rainwater harvesting simulation which runs throughout the entire year, the check dam simulation runs only during the critical dry season. Thus, it is essential to develop an accurate time period that represents the variation in average dry period throughout the Nilgiris District. For this purpose, the daily precipitation data for each of the 19 rain gauge stations were analysed to determine the longest dry period for each of the ten years. A sensitivity analysis was conducted incrementing the definition of a dry day by five millimetres from zero to fifteen (Appendix C, Tables C1-C4). As expected, the dry season length increased when the definition of a dry day was higher. The results from Appendix C, Table C1, which define a dry day as having less than one millimetre of rainfall, were used since they reflected a reasonable average dry period of 81 days equating to approximately three months which is typically found in the district. The next task was to establish regions within the Nilgiris District of equal dry season length for the purpose of user selection. Accordingly, the rain gauge stations were separated into the same regions used in the RWH harvesting simulation including the Plains, and the Southwest and Northeast Monsoon-influenced regions, to determine if a trend existed. It was found that the rain gauge stations in the Plains and Southwest Monsoon-influenced regions experienced similar dry seasons at 93 and 85 days respectively. However, the Northeast Monsoon-influenced region had a significantly lower dry season of 68 days. Since there was a significant difference in dry season length, it was decided to allow the user to choose from one of the three regions to run the check dam simulation. The length of simulation for each region was chosen based on a two-sigma factor that accounted for extreme conditions. For this method to hold true, a histogram was developed for each region to determine if the distribution of dry season lengths were normal. Figures C1 to C3 in Appendix C show a relatively normal distribution for each region. Table 21 describes the results of the two-sigma analysis where dry season lengths of 158, 146, and 112 were established for the Plains, SW Monsoon, and NE Monsoon regions respectively.

Table 21: Developing dry season lengths based on two-sigma analysis

REGION	μ	2σ	$\mu + 2\sigma$
Plains	92.8	64.9	158
SW Monsoon	84.6	61.8	146
NE Monsoon	68.0	44.2	112

Since the only contributing component of flow during the dry season is baseflow, the simulation is provided with an initial flow, and is decreased each day by a baseflow recession constant. To develop both these variables, a device for measuring streamflow is required to record data on a daily basis. A help file is available to the user for setting up a measuring device and developing streamflow data (Appendix F, Section 3). It is suggested to use a simple V-notch apparatus for measuring flow which has a calibrated set of flow rate values for different vertical distances above the bottom of the v-notch (Clark, 1988). The initial stream discharge should ideally reflect the saturated flow of water in the stream since the check dam simulation theoretically begins at the end of the monsoon period. The recession constant is created by measuring daily streamflow during a period of zero rainfall. The readings should be taken at the same time each day, and should cease once the measuring device is unable to accurately record the flow. A flow of zero cannot be inputted into the program since the program algorithms calculate a linear relationship between flow and time on a semi-logarithmic scale.

The final user input variable is the ratio of reservoir surface area to average depth, which is used in calculating daily evaporation. The units for evaporation are millimetres per day which require a reservoir surface area factor to create a volume per day estimate. Since the surface area changes with fluctuations in reservoir volume, a constant value would not accurately depict the true reservoir surface area over time. This factor is inputted by the user based on the land characteristics of the proposed site (ie. shallow and broad, steep and narrow). A guide to establishing the ratio is provided in the help menu (Appendix F, Section 3).

The user form for check dam simulation Option 1 is illustrated in Figure 22. If the user is unfamiliar with the three regions available for establishing the check dam location, a map is provided through a command button. Developing the recession constant is accomplished by clicking another command button that transfers the user to a table for inputting flow data. The user is prompted to enter the remaining input variables into textboxes on the original user form.

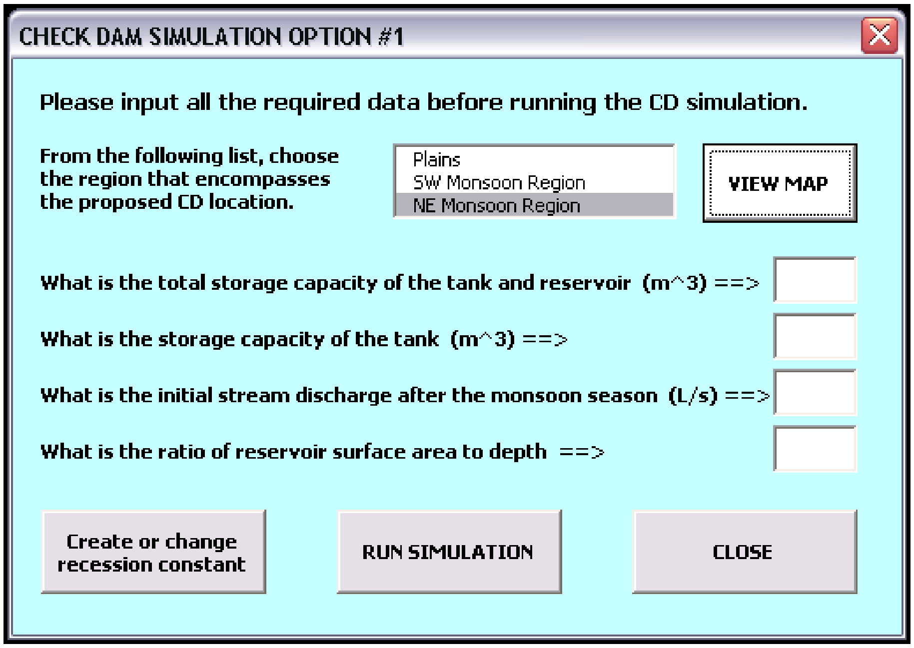

Figure 22: User form for Check Dam Simulation Option #1

4.4.3.2 Computer Processes

Once the requirements of the form are complete, the user clicks the run simulation button to initiate the sequence of algorithms used to produce the desired output. The computer processes that run the three simulation options are similar to the rooftop rainwater harvesting model but the length of simulation differs based on the dry period of the region selected. The dry period for the Plains and SW Monsoon regions extend from approximately the beginning of December to the end of April. However, the dry period for the NE Monsoon region is less than the other two regions by approximately one month. Since the average December precipitation for the NE Monsoon region is 150 mm as opposed to 32 mm for the other two regions, the dry period for the NE Monsoon region is January to April. Equations 4-11 to 4-16 are used to run the check dam simulation.

$$C_i = \min \begin{cases} S_{i-1} + q_i \\ D_i \end{cases} \tag{4-11}$$

$$Q_i = \max \begin{cases} S_{i-1} + q_i - V - C_i - EA \\ 0 \end{cases} \tag{4-12}$$

$$S_i = S_{i-1} + q_i - Q_i - C_i - EA \tag{4-13}$$

$$q_i = q_o e^{Ki} \tag{4-14}$$

$$A = \sqrt{(S_{i-1} - T)z} \tag{4-15}$$

$$R = V - T \tag{4-16}$$

where:

A = reservoir surface area (m^2)
C_i = consumption in period i (L)
D_i = water demand for period i (L/day)
E = rate of evaporation (mm/day)
i = day number
K = baseflow recession constant
R = reservoir storage capacity (L)
S_i = total storage at end of period i (L)
T = storage tank volume
q_0 = initial discharge (L/day)
q_i = discharge at day i after flow q_0 (L/day)
Q_i = spill in period i (L)
V = total storage capacity (L)
z = ratio of reservoir surface area to average depth

Equations 4-11 to 4-13 are a modified version of the equations developed by Heggen (1996) for calculating storage requirements of rooftop rainwater harvesting systems. The changes include substituting the rooftop rainwater inflow with stream inflow, and adding an outflow component for evaporation losses to the reservoir. Viessman and Lewis (1995) describe Equation 4-14 which is used to develop streamflow for the simulation. The evaporation loss is based on two variables including evaporation rate and reservoir surface area. Averages of the monthly evaporation rates measured by the Central Soil and Water Conservation Research and Training Institute in Ootacamund from the year 1960 to 2003 are used in the simulation (Appendix C, Table C5). Since the check dam simulation potentially runs only during the months from November to April, an analysis of data trends is carried out over these months. Appendix C, Table C6 and Figures C4 to C9 show no significant increasing trend in evaporation since the 95 percent confidence interval of each month's slope contains zero (Vega, Gaona, 1982). The reservoir surface area is calculated based on the volume of water in the reservoir and the ratio of surface area to average depth. The ratio is developed by the user and takes into consideration the physical characteristics of the proposed check dam site as described in the sub-module help-file (Appendix F, Section 3).

The computer processes used to develop the general algorithms across all three simulation options are described in the following points.

- The variables <flow>, <water consumption>, <spill>, <total storage volume>, <water demand>, and <evaporation> are declared as arrays.
- Other declared variables include <% reliability>, <storage capacity>, and <water tank capacity> and <ratio of reservoir surface area to depth>, which remain constant during each simulation.
- The flow data inputted by the user is transferred to a spreadsheet and is converted to a logarithmic scale. The SLOPE function in Microsoft® Excel is utilised to determine the baseflow recession constant based on the linear relationship between the logarithmic flow values and time. If there are missing data inputted by the user, the program takes the average of the two closest flow rates.

- One of three program codes is initiated depending on the region selected by the user. The Plains, SW Monsoon, and NE Monsoon regions run a daily simulation from November 24th, December 6th, and January 9th respectively to the end of April.
- The simulation runs through Equations 4-11 to 4-16 until the specified storage requirements or percent reliability are met.
- Depending on the simulation option chosen, the output from the simulation is transferred to Sub-module 2 worksheet, or a graph showing the relationship between storage capacity and reliability.

4.4.3.3 Computer Output

After running through the simulation option chosen by the user, the program presents the output on the standard template used for all sub-modules. Check dam simulation options one and two display the following output variables on the sub-module worksheet.

- storage requirements
- percent reliability
- monthly percent reliability
- recession constant
- R^2 value associated with the recession constant

The R^2 value should be utilised to assess the validity of the recession constant. Values ranging between zero and one represent the proportion of the variance in y that is attributable to the variance in x. In other words, the closer the R^2 value is to one, the better the linear correlation between the two variables. If the R^2 value is below an acceptable limit judged by the user, more accurate flow measuring equipment may be needed. Utilising the storage requirements from the check dam simulation model involves further field work to develop the design specifications of the dam. As opposed to standard sizes of tanks used for capturing rainwater, a dam reservoir has complex geometry that requires an estimate of the elevation level needed to hold the desired volume of water. The results of this analysis greatly influence the cost required for dam construction, and the impact of the dam on the surrounding ecosystem.

The results of Simulation Option 3 graphically display the relationship between percent reliability and storage requirements on a separate worksheet. The minimum potential reliability levels for each region are calculated based on the percentage of non-simulation days during the year. As such, the ranges of output for each region are described in Table 22.

Table 22: Output specifications for check dam simulation option three

Region	Simulation Length	Min. Percent Reliability	Percent Reliability Values used in Simulation Option #3
Plains	158	57	57, 60, 70, 80, 85, 90, 94, 98, 100
SW Monsoon	146	60	60, 70, 80, 85, 90, 94, 98, 100
NE Monsoon	112	70	70, 80, 85, 90, 94, 98, 100

4.4.3.4 Assumptions and Simplifications

The rainwater harvesting model runs through a ten year daily simulation of precipitation data to develop storage requirements. Using a similar scheme to run a check dam simulation requires extensive streamflow data developed through a calibrated rainfall-runoff model. Since an accurate record of hydrological data is not available for small catchments in the Nilgiris District, only the critical dry period is taken into consideration. It is assumed that a two-sigma approach to developing dry period length incorporates the years with extreme conditions. The assumptions and simplifications for the check dam simulation are further described within the context of user input, computer processes, and computer output.

The most important physical characteristic to establish by the user for the check dam simulation is the rate at which flow decreases with no recharge from precipitation. For most watersheds, this recession constant remains approximately stable since the watershed geology does not change greatly over time (Viessman, Lewis, 1995). As such, it is assumed that for small catchments throughout the Nilgiris District, the recession constants developed through the analysis of gauged streamflow data represent the conditions over an extended period of time. In addition to the recession constant, an initial discharge rate is required that reflects a realistic transition flow between monsoon and dry periods. An attempt to measure the saturated flow rate of the stream is assumed to represent this transition period. The economic conditions of the district make it difficult to measure the saturated flow rates of small streams using groundwater modelling software. To obtain a reasonable estimate, numerous flow rates are recorded during the monsoon period at times when the ground is likely saturated, and when the only component contributing to the streamflow is baseflow. For these conditions to hold true two assumptions are made: the flow measurements are recorded after a period of extensive rain when the ground is assumed to be saturated; and the time of concentration for small catchments is minimal resulting in the stream's quick transition to baseflow. A study by the CSWCTRI (1982) shows that the time of concentration for all watersheds in the Nilgiris District is less than three hours (Appendix B, Table C7). Therefore, if streamflow is measured a day after a series of heavy rain days, the majority of flow will be in the form of baseflow.

After incorporating the stream's contribution to increasing the storage in the reservoir, other components such as evaporation have an opposite decreasing effect. Evaporation losses take into consideration the rate of evaporation on a daily basis, and the surface area susceptible to evaporation. To account for a changing reservoir surface area over time, a ratio is developed by the user that characterises the physical dimensions of the check dam location. To simplify the geometry of the land, it is assumed that a linear relationship exists between the reservoir's average depth and surface area. This estimate provides details on whether the land is flat and broad resulting in greater evaporation, or steep and narrow resulting in minimal evaporation. Overall, it simplifies the process for developing evaporation losses allowing for easy integration into the simulation computer code.

The computer processes used to develop the simulation output are conceptually described as a central storage module with numerous inflows and outflows. Before running Simulation Options 2 and 3, the central module must be assigned a starting storage capacity. The estimate is based on similar concepts to Equation 4-10 which assesses the amount of water required by the village during the dry season. The variables used in the calculation include village water demand, percent reliability, and estimated length of dry period for which the reservoir runs dry. It is assumed that the reservoir is at full capacity at the beginning of the simulation since the starting point marks the end of the monsoon period when water is plentiful. To simplify the central module, the reservoir and water tank are considered a single unit since they are connected by a pipe. For this simplification to hold true, the pipe must have a valve disconnecting flow to the water tank to allow for overflow at the reservoir level. Unfortunately, the overflow systems in the Nilgiris District typically occur at the water tank near the village since the infrastructure is not equipped with a valve to stop flow. This poor construction practice is addressed in the help menu of the sub-module to ensure proper construction of new check dams (Appendix F, Section 3). To minimize losses in the reservoir, it is assumed that an insignificant volume of water is lost to infiltration. The check dams constructed within the Nilgiris District are typically located in areas of high slope where the soil depth is low. Soil is excavated to a depth that reaches either the bedrock or hard soil that has low hydraulic conductivity. If the check dam has a high structural integrity, the amount of undesirable water flowing through is minimized. After the inflows and outflows to the system are accounted for, a failure occurs when the water consumption is less than two-thirds of the ideal village water demand. This number was developed through a survey and meetings with the local population. A majority of the local population said they could accept consuming one-third of their ideal demand.

The most significant simplification made to the check dam simulation is using the critical dry period to develop design specifications as opposed to a yearly analysis. As a result, there is a lack of output for percent reliability during the monsoon period. To account for the monsoon period, it is assumed the villages receive an ideal demand during this time. Villages that have check dams as a primary water source typically claim that the dry season is the only time of year where an inadequate supply of water is encountered.

4.4.4 Sub-module 3: Reservoir

4.4.4.1 User Input, Computer Processes, Computer Output

A simple method is used in NRWS for assessing a reservoir's ability to provide an adequate supply of water to a rural village. The method was developed by the United State Agency for International Development (1982) to help technical staff working in developing countries across the world. In order to input data and run the calculations for Sub-module 3, a user form is activated through a hyperlink. Dimensions of the reservoir are required from the user to run the algorithms of the sub-module including dry season reservoir area, and greatest reservoir depth during dry season. The equations used in the sub-module algorithms are Equations 4-17 and 4-18 (USAID, 1982).

$$AD = 0.4GD \tag{4-17}$$

$$V = 0.8 * SA * AD \tag{4-18}$$

where,
AD = average reservoir depth during dry season (m)
GD = greatest reservoir depth during dry season (m)
V = effective reservoir volume after accounting for losses (m^3)
SA = reservoir surface area during dry season (m^2)

Comparing the effective reservoir volume to water demand ensures enough water is available to the rural village. If the reservoir can provide an adequate supply of water to the village over a six-month time period between December and May, it is given 100 percent reliability; otherwise these months receive zero percent reliability. The calculation utilises the water demand input from the Module 1 worksheet to compare with effective reservoir volume. Between the months of June to November, the heavy rainfall caused by the two monsoon periods enables the villages to achieve 100 percent reliability.

The output template for the reservoir source provides details on the potential yield, but also allows the user to gauge its impact on the environment and hydroelectric production within the district. The output variables are described in the following points.

- **Effective Reservoir Volume**: Total volume of the reservoir minus potential losses from evaporation and infiltration.
- **Six-month Village Water Demand**: Total volume of water necessary to meet the demands of the rural village between December and May.
- **Percentage of Reservoir Consumed over Six-months**: The percentage of effective reservoir volume used by the rural village during the six month dry period with no recharge from precipitation. A lower percentage of water extracted from the reservoir decreases the impact on the surrounding environment and hydroelectric production. This output variable is useful in Module 4.

- **Overall and Monthly % Reliability**: Standard output across all potential water sources used for comparison purposes.

4.4.4.2 Assumptions and Simplifications

Assessing the potential yield of rainwater harvesting systems or check dams is important due to fluctuating levels of water throughout the year. On the other hand, water quality is the main focus in large reservoirs since they typically maintain an adequate volume to supply small-scale rural systems. As such, a simplified method is acceptable to estimate the potential yield from the reservoir source. More complex methods of analysing reservoir volumes involve lumped conceptual rainfall-runoff models that require a plethora of hydrological data not available in the district. Substantiating a simplified method requires assumptions that are realistic to the conditions of the Nilgiris District. Most of the assumptions are described in USAID (1982) including:

- the effective reservoir volume must be greater or equal to a six-month village water demand;
- average reservoir depth is two-fifths the greatest depth; and
- losses in the reservoir caused by evaporation and infiltration are one-fifth the reservoir volume.

Having a six-month dry season length is a reasonable factor of safety since the average dry season in the Nilgiris District is between three and four months. The monsoon period supplies an average of 1200 millimetres of rainfall justifying the assumption that the months between June and November achieve 100 percent reliability.

4.4.5 Sub-module 4: Spring

The methodology used to develop the water yield for a spring source is identical to the check dam simulation outlined in Sub-module 2. A number of key details validate the correlation between the two source methodologies. First of all, both methods run simulations during the critical dry season where only baseflow is considered in recharging the storage unit. The spring source does not require the separation of baseflow from streamflow since all water travels underground. Therefore, a stable recession constant can be developed under the assumption that the watershed geology remains constant (Viessman, Lewis, 1995). The techniques used to develop measured flow rates and other input variables for each source are different as described in the help files (Appendix F, Section 5). Secondly, the storage units used to capture water at the check dam and spring sources are a reservoir and pond respectively, both of which are exposed to evaporation losses. When spring water is located and found to be a viable source, a pond is typically dug in the surrounding area (Figure 23).

For the spring and check dam simulations, comparing the overall percent reliability with other sources does not suffice. Failure days occur in one concentrated time period whereas sources such as rainwater harvesting have a wider dispersion over time. For example, it is more difficult for a village to deal with a thirty day drought as opposed to three days of drought per month for ten months. The analysis of monthly percent reliability levels helps to assess this factor.

Figure 23: Pond dug to store water from a spring

4.4.6 Sub-module 5: Well

4.4.6.1 User Input, Computer Processes, Computer Output

In India, approximately 85% of rural villages rely on the vastly depleting groundwater source for domestic purposes (Lal, 2002). Many rural villages in the Nilgiris district currently use groundwater as their main source. Water extracted from the ground for rural water supply is typically drought resistant due to the slow movement of water through the ground. However, extracting groundwater very often has high extraction costs, high remediation costs if problems arise, and environmental consequences from depleting the local aquifers. “To use groundwater resources efficiently while simultaneously permitting the maximum development of the resource, equilibrium must be established between withdrawals and replenishments” (Viessman, Lewis, 1995). Economic and environmental implications restrict the use of groundwater to dug wells in unconfined aquifers in the Nilgiris District, supporting the efforts to ensure withdrawals are not greater than recharge.

Unlike the other potential sources in NRWS, the well source transfers directly from the main Module 1 worksheet to a user form, as opposed to an exclusive worksheet. The user form lists five features to help determine whether the conditions of the well location are suitable (Table 23). Since tapping into the groundwater resources has strong environmental consequences, an emphasis is placed on establishing strong grounds for considering the source. If the scores are mostly between one and three, the user clicks on a button at the bottom of the form that takes the well source off the list of potential sources. If the score for the features in the form are mainly between three and five, the user clicks on the option to estimate the potential yield.

If the user decides to proceed with estimating the potential yield, another user form is initiated which prompts the user for four variables: maximum pumping rate at the end of the dry season; maximum pumping rate during the monsoon season; dry season length; and typical starting month of dry season (Figure 24). It would be ideal to carry out field work on the proposed location, but with economic constraints this may not be possible. The next best solution is testing a nearby well that has similar hydrogeological characteristics. A help file is referred to on the user form, describing the methodology for measuring the pumping rates (Appendix F, Section 6) which uses a method developed in House and Reed (1997). Local knowledge should be utilised to establish the dry season characteristics.

Table 23: List of features and scores for assessing well location feasibility

SCORE	5	4	3	2	1
FEATURES	**Positive**				**Negative**
Geological[1]	Unconsolidated sand and gravels in mountain-flanked valleys or in existing river valleys	Extensive sequences of sedimentary rock with sandstone beds	Igneous or metamorphic rock with faults and associated fracture zones	Igneous or metamorphic rock outcrops with extensive weathering	Clays and un-weathered rock
Topographical and Vegetation[1]	High mountainous areas with lush (all year round) vegetation in the valleys	➔	Undulating areas with vegetation cover	➔	Flat desert areas with negligible vegetation cover
Climatic and hydrogeological[1]	High rainfall (> 1000 mm per year)	➔	Average rainfall (700 mm per year)	➔	Low rainfall (<250 mm per year)
Human[1]	Large settlements Successful agriculture, often large scale	➔	Scattered settlements Medium-scale agriculture	➔	Limited settlements No agriculture
Surface water characteristics[2]	Nearby streams are perennial Well is located in strata uphill from known spring	➔	Nearby streams dry up for short period during the year Well is located on floodplain or close to a lake	➔	Nearby streams dry up for extended period during the year No surface water sources nearby

Source: [1]House, Reed (1997), [2]Watt, Wood (1976)

Upon clicking the 'Calculate Percent Reliability' button, a set of algorithms is initiated which performs the functions listed in the following bullets.

- Monsoon and dry season pumping rates are transferred to a worksheet in a monthly order according to the specified dry season length and starting month.
- Daily water demand on a monthly basis inputted by the user on the main Module 1 worksheet is transferred to the well calculation worksheet.
- Pumping rates are converted from L/min to L/day in order to compare with the units of water demand.
- If the monthly maximum pumping rate exceeds demand, a 100% reliability is assigned, otherwise the appropriate percentage is calculated.

The Module 1 worksheet presents a standardised set of output variables for the potential sources. Accordingly, once the monthly and overall percent reliability are calculated for the dug well sub-module, the values are placed in the Module 1 worksheet table alongside the other potential sources.

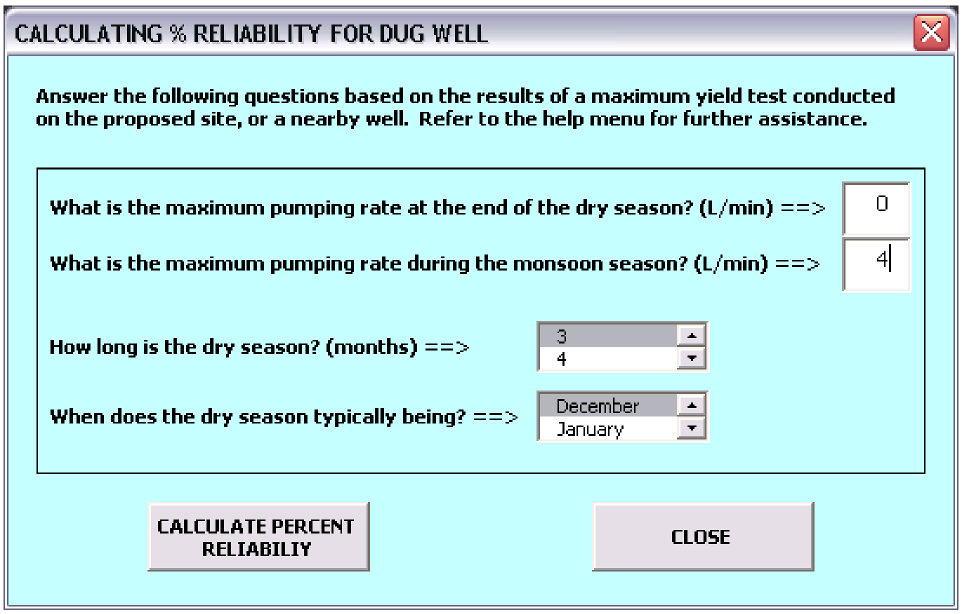

Figure 24: User form for inputting data to calculate yield of dug well

4.4.6.2 Assumptions and Simplifications

Groundwater is difficult to assess due to its complex characteristics that require extensive below-grade field work. Due to economic and technical limitations in the Nilgiris District, a number of assumptions and simplifications help to shape the structure of the sub-module. When the sub-module is initiated, the user is presented with a table that lists five important features, and ranks different conditions within the feature between one and five. Along with a scoring system is typically a list of appropriate courses of action for different total scores. The simplified method used in this case prompts the user to qualitatively compare the number of high scores to low scores in order to make a judgement call. House and Reed (1997) use the same method for evaluating aquifer characteristics.

If the well characteristics are adequate for development, the user is transferred to a form for estimating the well yield which uses a simplified method based on maximum pumping rates (House, Reed, 1997). Since the district has a monsoon and dry season, a pumping rate is measured for each season to characterise fluctuations throughout the year. Still, relying on two pumping rates to accurately depict the true conditions of the well location is not sufficient. As such, a number of assumptions are made to increase the validity of the method including:

- if site-specific pumping rates are not economically feasible, the average of at least two nearby wells is required to establish monsoon and dry season conditions;
- the pumping rates are decreased by a safety factor of two to account for the inaccuracy of the method;
- it is assumed the well is dug at the end of the dry season when water table levels are at their lowest.

4.5 Module 2: Capital Costs

4.5.1 Input Variables

The limiting factor for implementing sustainable water supply technology in rural areas of low economic status is funding. The initial capital cost of constructing a new water supply system is one component of the overall cost which must be available from the village and external funding agencies. Typically in the Nilgiris District, the Tamil Nadu Water and Development Board assists in the funding for implementing rural water supply technology. The input variables for the capital cost criterion are two tiered, where the user qualitatively inputs a weight and score for each potential water source based on quantitative user input that calculates an estimated total capital cost for each source.

The quantitative cost components associated with the overall capital cost of each source are presented in separate tables, accessible through the Module 2 worksheet. Material costs for all government works are developed on a yearly basis for each district in the State of Tamil Nadu and presented in a document called the Standardised Schedule of Rates. All costing rates used in NRWS were taken from an Agricultural Engineering Department (2004) report and Sahu (2002) which used the 2003 and 2002 Nilgiris District Standardised Schedule of Rates respectively. Three sections of the costing tables are consistent across all water sources including: construction of storage unit; pipeline and pump; and water treatment.

Storage tanks for rainwater harvesting units are located at each household as opposed to every other source that has one highly elevated storage tank which distributes water to a village. Four materials commonly used in the Nilgiris District to store different quantities of water are outlined in Table 24.

Pipelines used to distribute water from the point source to the villagers are B-grade galvanised iron pipes and are available in various sizes depending on the estimated maximum flow of water. The sizes range from three-quarter inch to two inch. If pumping is required for distribution purposes, a motor shed is built to protect the pump and house the necessary equipment for pump maintenance.

Water treatment practices vary across the district depending on the quality of water available to the local population. In most cases, sporadic doses of chlorine are the only treatment applied to rural water supply systems. A lumped sum costing rate is provided for each potential water treatment process as opposed to listing the base materials since their construction practices are standardised across the district. The three available processes include a small filter, a large slow sand filter, and a sedimentation tank with weirs. The chlorination process is considered as a variable cost under operation and maintenance.

Table 24: Storage tank costing and design parameters for the Nilgiris District

STORAGE TANK MATERIAL	TYPICAL CAPACITY RANGE	COST (Rs./L)
Reinforced Concrete	> 50,000 L	2.5
Brick/Stone Masonry	15,000 L to 50,000 L	4
Ferrocement	4,000 L to 15,000 L	1.5-2
Plastic	< 4,000 L	3

Source: Sahu (2002)

Besides the construction materials consistent across all five water sources, a unique set of cost components identifies materials required for each source. Rooftop rainwater harvesting necessitates a rooftop layout that is conducive to directing the flow of water into a storage unit. Materials such as gutters, down pipe, and first-flush pipe support the flow of water across the rooftop. The containing layer of a check dam must be at such a depth that is technically possible to carry out excavation at a reasonable cost (Hanson, Nilsson, 1986). Excavation prices along with different concrete mix and plastering costs make up the cost components of the check dam source. Depending on the nature of a spring and the physical characteristics of the surrounding land, the development of this source may be as simple as excavating material to build a pond, or may require structural support to contain the water. Materials for the spring source are similar to the check dam source except for the addition of sand and gravel which is used if a spring box is constructed. Tapping water from a reservoir involves the construction of an intake structure that maintains a horizontal position far enough below the surface to minimize the presence of floating materials, and an adequate distance from the bottom to mitigate the intake of settled material. The equipment used for this purpose is an anchor and floating device. There are two main methods used for well construction: borehole wells (augured) are typically drilled to great depths to tap into deep aquifers; and dug-wells are used in areas were the water table level is high enough to reach through manual digging (US AID, 1982). The only method used for rural water supply in the Nilgiris District is a dug-well that has a two or three metre diameter caisson with well covering.

4.5.2 Computer Processes, Computer Output

Accessible only from the main menu of NRWS, Module 2 has a two-level system for carrying out the task of evaluating capital costs of potential water sources. Level one represents the central Module 2 worksheet and is set up in table format to provide the user with the tools needed to accurately assess the criterion. The first table outlines the total capital cost for each water source and enables the user to enter a score, while the second table is a set of guidelines to help the user assign reasonable scores to each source. Ranging from one to ten, the score descriptions in the second table assess whether the source is economically feasible, with a lower score indicating an increased reliance on external assistance. The lowest possible score specifies a water source that is not economically feasible after assistance from all possible funding agencies.

From the central Module 2 worksheet, the user has the option of following five links to input the capital cost components for each potential water source. Instructions are provided to the user on inputting the number of units for each cost component in the lighter cells of the worksheet table. The darker cells describe the construction materials/activities required to implement each water source, and their respective unit cost (Figure 25). If a rainwater harvesting simulation has been run during the execution of Module 1, the average required storage capacity per household along with the number of tanks is transferred to Module 2. The user has the option of applying these design specifications, or can change them accordingly. A set of links on each worksheet enables the user to view all the cost components and total capital costs, or return to the central Module 2 worksheet.

Sl #	DESCRIPTION OF WORK/MATERIAL	Unit	Unit Cost (Rs.)	Number of Units	Amount (Lakh)
	PIPELINE AND PUMP				
a	Drinking Water Pipeline, B-Class (2")	20ft	975		
b	Drinking Water Pipeline, B-Class (1.5")	20ft	675		
c	Drinking Water Pipeline, B-Class (1")	20ft	520		
d	Drinking Water Pipeline, B-Class (3/4")	20ft	330		
e	10 Hp Electric Motor	No.	40,000		
f	Motor Shed	No.	50,000		

Figure 25: Example costing table for Module 2

The output for Module 2 can be broken down into the cost of each material used in the construction process, and the total capital cost for implementing each water source. This information is posted directly on each level-two worksheet, and the total capital cost is also transferred to the central Module 2 worksheet for the purpose of comparing the potential water sources. If the user has not input the number of units for each cost component, the total capital costs for the respective water source are left blank on the central Module 2 worksheet.

4.5.3 Assumptions and Simplifications

There are two categories used to address the assumptions and simplifications of Module 2. The first is directly related to the actual material costs, while the second addresses the exclusion of certain cost components that under different circumstances would seem necessary. Since the Nilgiris District has a standardised pricing system for water supply construction materials, it is assumed that the price listings in NRWS are representative of the true costs at every place of distribution in the district. Over time, the costs can change due to reasons such as an element of competition that drives prices down (Gould, Nissen-Peterson, 1999). Therefore, the pricing scheme for NRWS should be adjusted every time a new Standardised Schedule of Rates is printed for the Nilgiris District.

Under the second category, the cost components for developing each water source do not include design and project management costs, or labour costs. In the Nilgiris District, a trained engineer paid by the government overlooks the construction of rural water supply systems. As such, with adequate involvement of government agencies and NGO's, there is typically no cost associated with design and project management. Labour costs are significantly reduced by utilising local labour since there is a lower cost associated with hiring locals as opposed to outsourcing to larger companies (Batteson, Davey, Shaw, 1998). More often than not, the local population is willing to offer free labour to benefit the social status of the community.

Specifically relating to rainwater harvesting, the roofing cost is not included in the overall capital costs of the system since this component is constructed primary for reasons other than collecting rainwater (Thomas, 1998). However, the roofing quality of houses in poorer villages may be unfit for harvesting rainwater, making it necessary to include the roofing costs in the overall cost breakdown. If this is the case, rainwater harvesting would most likely not be economically feasible (Thomas, 1998). This issue is addressed in the guideline table of the central Module 2 worksheet.

4.6 Module 3: Cost and Ease of Operation and Maintenance

4.6.1 User Input

Creating mechanisms to effectively operate and maintain a water source ensures system longevity and high performance. Research has shown that: inaccurate development of operation and maintenance costs often leads to insufficient funds to sustain a project; replacement costs are rarely taken into consideration resulting in problems when infrastructure requires renewal; and subsidies are inadequately targeted and rarely benefit the vulnerable members of society (Deverill et al, 2002). Module 3 of NRWS organizes information pertinent to deciding whether a village is capable of operating and maintaining potential water sources based on the economic contributions from villagers. As such, the user input variables are split into two categories: the operation and maintenance cost components; and, the contingent valuation variables indicating the villagers' willingness to pay for improved services.

Based on a standardised cost component sheet for all water sources, the user inputs the number of units for each material/work that is required to sustain each source over a twenty-year lifespan. Since the operation and maintenance costs are subject to unknown conditions over time, an estimate of each cost component is developed through historical data based on past rural water supply systems, and quantitative assessment where possible. The unit cost for materials/works listed in Table 25 are from the Nilgiris District 2003 Standardised Schedule of Rates, and are separated into four sections including pump, storage unit, pipeline, and technical assistance/manual labour. From the list of cost components, the user must decide which ones apply to each potential water source.

Table 25: Operation and Maintenance Cost Components

	DESCRIPTION OF WORKS/MATERIAL	COST DESCRIPTION	UNIT	UNIT COST (RS.)
1	**PUMP**			
a	Spare/replacement parts	10 yr. (refit)	No.	300
b	Electricity	Recurrent cost	Units/yr	5
c	10 Hp Electric Motor	20 yr. (replacement)	No.	40,000
2	**STORAGE UNIT**			
a	Fix leaks (replace flooring in tank)	20 yr. (replacement)	m^3	270
b	Chlorine	Recurrent cost	m^3_{water}	2
3	**PIPELINE**			
a	Replacement of 2" pipeline	20 yr. (replacement)	20 ft	975
b	Replacement of 1.5" pipeline	20 yr. (replacement)	20 ft	675
c	Replacement of 1" pipeline	20 yr. (replacement)	20 ft	520
d	Replacement of ¾" pipeline	20 yr. (replacement)	20 ft	330
e	Fix leaks	10 yr. (refit)	No.	200
4	**TECHNICAL ASSISTANCE/ MANUAL LABOUR**			
a	Technical Specialist	10 yr. (refit)	Visits	200
b	Shramadhan	Recurrent cost	Person	15
c	Local resident (daily operation)	Recurrent cost	No/yr.	6,000
d	Pipe Layer or Bar Bender	10 yr. (refit)	Day	126

Section 1 of the costing table provides the specifications for fixing, operating, and replacing electric motors used to pump water to a storage unit. The government has established a subsidised electricity rate for rural water supply that is below the competitive market price. Included in Section 2 is the cost of fixing a storage tank leak which involves replacing the entire flooring system. The material costs associated with this task include sand (Rs. 1140/m^3), 1.5" rebar (Rs. 700/m^3), and cement (Rs. 175/bag), where the average cost has been found to be Rs. 270/m^2. Section 3 accounts for the replacement of standard B-grade galvanised iron pipelines of varying size after their estimated twenty-year lifespan, and addresses the fixing of leaks resulting from daily wear and tear. The word 'shramadhan' in Section 4 is a combination of the two Tamil words, shrama meaning labour, and dhan meaning gift. This word is used to describe a day where the community provides free labour to help clean and fix their drinking water infrastructure. A lunch is provided to the labourers which is paid for by the village association. Besides the upkeep of a village water supply due to shramadhan, there is one villager who is paid a yearly salary of Rs. 6,000 to carry out the daily operation and maintenance activities.

Since the operation and maintenance costs are spread over the twenty-year lifespan of the rural water supply, the time value of money is an important factor to consider. Depending on the inflation and interest rates of the local and international economy, the value of one Rupee today will purchase more materials than one Rupee in ten years time (Deverill et al, 2002). Therefore, NRWS prompts the user for the current interest rate to ensure that operation and maintenance costs can be paid for in the future.

There is strong evidence that suggests rural villagers are willing to make significant economic contributions to receive service levels they desire (Deverill et al, 2002). The villagers' willingness to pay for improved services is correlated with many factors including: households with higher education; households presently consuming larger quantities of water; and households displeased with present water sources (Hopkins, 2004). A contingent valuation survey should be carried out in each village upgrading their water source to assess the villagers' willingness to pay for an improved service. Through this process, the yearly funds available for operating and maintaining a water source can be maximised by finding the level at which yearly household fee and percentage of households willing to pay the fee, produces the largest revenues. However, a subsidy should be considered for households in the lower economic bracket in order to increase the number of households using the improved service (Hopkins, 2004). As such, NRWS offers a user input table with three possible combinations of fees to account for subsidies. Using the contingent valuation survey is effective in determining the financial feasibility of operating and maintaining a water source, but must be carried out by trained field staff who are able to interact with every socio-economic group within the village.

4.6.2 Computer Processes, Computer Output

Developing the computer processes for Module 3 are more involved and complicated than the capital cost criterion in Module 2 for two reasons. Initial capital costs for rural water supply in the Nilgiris District are typically funded by government agencies, whereas the operation and maintenance activities are the responsibility of the local population. Thus, the willingness of the villagers to pay for improved services is an important aspect of assessing the feasibility of each potential water source. Also, since the operation and maintenance costs are dispersed across a twenty-year infrastructure lifespan, the time value of money must be taken into consideration.

When entering the central Module 3 worksheet, clear instructions inform the user to first input costing information on all potential water sources before assessing the feasibility of each source. A hyperlink table containing each available water source transfers the user to separate worksheets where a full list of operation and maintenance cost components is available. If the Module 1 water source yield criterion has been run for any potential water source, information for the chlorine cost component in Module 3 is automatically updated since it directly relates to the amount of water being consumed by the village on a yearly basis. Changes can be made by the user in cases where chlorine is not used in water treatment, or if chlorine is available to the village at no cost.

After the cost component worksheets are complete, the user must assess whether the village can economically sustain the potential water sources based on the total cost of operating and maintaining each system. This process is first initiated by entering a user form through a hyperlink which prompts the user to input information relating to the villages' willingness to pay and the local interest rate (Figure 26).

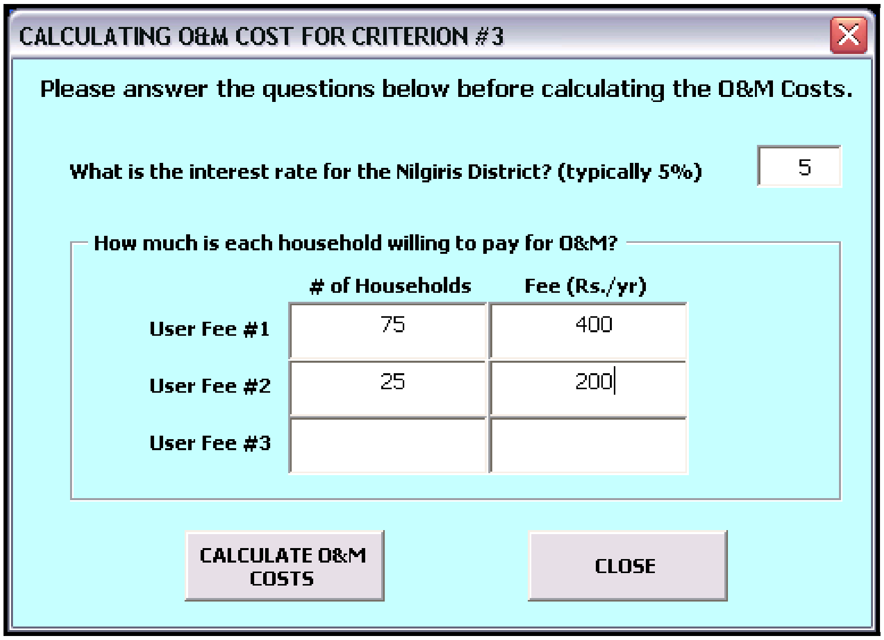

Figure 26: Standard UserForm in Module 3 for calculating total O&M costs

Once the 'CALCULATE O&M COSTS' button is clicked, a series of algorithms calculates the recurrent, ten-year refit, and twenty-year replacement costs for each water source, the last two of which are adjusted for the time value of money using Equations 4-19 and 4-20 (Ross et al, 2002).

$$AF(r,n) = \frac{[1-(1+r)^{-n}]}{r} \tag{4-19}$$

$$Annuity = \frac{CurrentValue}{AF(r,n)} \tag{4-20}$$

where,

AF = Annuity Factor
r = interest rate
n = number of years

These equations determine the total yearly amount of money needed from the village to pay for recurring yearly costs and the lumped costs associated with refitting and replacing components of the water supply system in the future. Since the annuity for the refitting cost extends over the first ten years, the respective total costs during this time period are greater than the final ten years which only takes into consideration the replacement and recurrent costs. Therefore, the output variables transferred to the main table on the central Module 3 worksheet are total annual costs for years 0-10 and 10-20, average annual costs, and the percentage of average annual costs the villagers' are willing to pay for the operation and maintenance of each potential source.

The output variables of Module 3 quantitatively aid in the process of assigning a score to each potential water source for the purpose of evaluating the operation and maintenance criterion. To further assist the user, a qualitative set of guidelines in the central Module 3 worksheet provide insight on effectively assigning scores based on the costing output variables, and also describe three measurable factors that encompass the ease of operation and maintenance. High level technologies necessitate the need for specialised personnel who can fix water supply systems if problems arise. As a result, the local management team must have the capacity to deal with such circumstances otherwise the system will inevitably break down. Next, if the water supply system relies on electricity to provide water to the local population, the unpredictability of the power grid in the district creates uncertainty in the performance level. Lastly, the ease of operating and maintaining a water source depends on its distance to the village. Many villages in the Nilgiris District do not have nearby water sources relying on pipelines to transfer water from far off sources such as check dams. Water sources not located in the general vicinity of the village are less likely to be maintained on a regular basis, increasing the chance of premature technical malfunctions.

4.6.3 Assumptions and Simplifications

The selection of operation and maintenance cost components for Module 3 is simplified through the exclusion of components that are not applicable to the Nilgiris District. Since the equipment and practices used for rural water supply in the Nilgiris District are standardised, an unambiguous list of cost components is established as opposed to giving the user flexibility. An example of this is the use of electric motors in place of gas motors to pump water. Even though a gas motor could be used, it is not a standard practice due to the accessibility of electricity in the District from hydroelectric power plants. The cost components associated with the replacement of the water source infrastructure after the twenty-year lifespan is assumed to be paid for by the Tamil Nadu Water and Development Board and are not included in Module 3. As mentioned in Module 2, the Nilgiris District has a standardised pricing system for water supply materials. It is assumed that the price listings in NRWS are representative of the true costs at every place of distribution in the district; however, the pricing scheme for NRWS should be adjusted every time a new Standardised Schedule of Rates is printed for the Nilgiris District.

Since Module 3 is forecasting the probability of future events, assumptions must be made regarding the interest rate over time and longevity of the water supply infrastructure. Based on the methodology developed in Deverill et al (2002), the operation and maintenance costs are assumed to have three components as listed in the following points.

- A recurring yearly cost associated with the consistent upkeep of the water supply infrastructure.
- A refitting cost mid-way through the expected lifespan which repairs major maintenance problems.
- The cost of replacing components of the distribution system after their expected twenty-year lifespan.

Separating costs into these three components allows for a simplified estimate of the time value of money over the infrastructure lifespan. With regards to the interest rate, it is assumed to remain steady over the twenty year infrastructure lifespan even though fluctuations are likely.

The goal of identifying the villagers' willingness to pay for improved services is a daunting task. Not only does the process require surveying every socio-economic class in the village, but a costing structure must also be developed that provides safe drinking water to every villager while not economically burdening the vulnerable members of society. NRWS provides the framework for inputting cost structures for different socio-economic classes within the village, but assumes the process to develop the user-fee system is performed effectively.

4.7 MODULES 4/5: IMPACT OF DEVELOPMENT AND POLITICAL/LEGAL CONSTRAINTS

4.7.1 User Input, Computer Processes, Computer Output

The qualitative nature of Modules 4 and 5 minimize the need to develop complex algorithms for comparing potential sources. User input is influenced by assessing a list of potential variables that would inhibit the ability of the water source to perform at an acceptable level. After the user has input a score for each potential water source and applied a weight representing the importance of each criterion, the information is transferred to the evaluation worksheet where the user can view the DSS results for the village.

Potential environmental impacts include any actions that jeopardize the sustainability of the water cycle, and alterations to the physical geography that negatively affect the local flora and fauna. Constructing a reservoir on a mountain stream could engulf a large area of land if the terrain is wide and broad as opposed to narrow and steep. Also, drilling deep into aquifers could lower the water level significantly depleting the groundwater resources. These impacts and their consequences should be understood before developing the source. At the same time, developing certain sources may go against the cultural or religious norms of the local population, or may not be aesthetically pleasing. To help the user address both the environmental and human impacts of development, a number of variables are transferred from the sub-modules of Module 1 to the Module 4 worksheet as described in Table 26.

Table 26: Variables transferred from Module 1 to Module 4

Source	Transferred Variable	Impact Description
RWH	Average household storage requirement	• large storage units beside households may not be aesthetically pleasing to the villagers • required storage size may not spatially fit the dimensions of the village
Check Dam	Reservoir storage requirement	• land encroached by the reservoir may negatively affect local flora and fauna • downstream villages may rely on stream water
Reservoir	% of reservoir used by village over six months	• consumption of water during the dry season may significantly reduce reservoir levels
Spring	Spring pond storage requirement	• land encroached by the reservoir may negatively affect local flora and fauna
Dug Well	Depth of water table	• low water table levels may indicate poor groundwater conditions

Subsequent to viewing the variables transferred from Module 1, the user can effectively assign a score through a set of guidelines that describe reasonable scenarios for a range of values. Besides the general guidelines addressing the overall level of impact, specific attention is placed on the importance of minimizing the impacts on groundwater resources which play a key role in sustaining the livelihoods of most occupations in the district.

In addition to the normal procedure of assigning scores and weights to each criterion, Module 5 has the ability to veto a potential water source if it does not fall into the legal or political framework of the local government (House, Reed, 1997). Such circumstances arise when the source is located on private property with an uncompromising owner or on government conservation land where development is prohibited. A veto clause is necessary only for Module 5 since the other criteria deal with economic conditions which can be overcome, soft issues which can be adapted to, or water quantity/quality conditions that can be improved upon or accepted. Potential water sources can be vetoed through a user form initiated from the Module 5 worksheet which provides a list of the sources along with various circumstances for rejection (Figure 27). When the user exits the form, the information is transferred to the final DSS results worksheet where a clear message warns the user to reject the vetoed water sources.

A help-file and guideline table are also available to users who wish to assess the spectrum of possible scores for the Module 5 criterion (Appendix F, Section 10). The help-file lists the following questions for the user to consider.

- Who owns the land and what is the procedure to obtain permission to abstract? If the source is not located on common land, would negotiations help to solve the problem?
- Are there security problems at the source that would affect the safety of the local villagers?

- Is the local government allowing industries to pollute the water resources being considered for rural water supply leading directly or indirectly to long-term and irreversible effects on the quality of water?

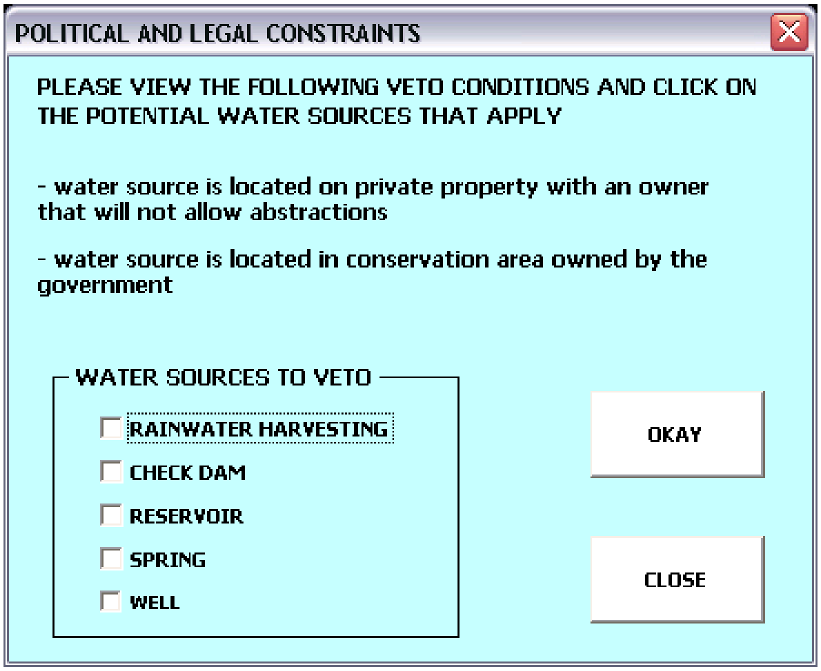

Figure 27: UserForm that allows user to veto sources that are not legally feasible

4.7.2 Assumptions and Simplifications

Since the information presented in the Module 4 and 5 help-files do not direct the user along a specific course of action, a simplified qualitative approach is imbedded in the development of the two modules. As such, it is assumed that the user has the ability to thoroughly research the questions addressed in the help-files for both Module 4 and 5.

4.8 MODULE 6: WATER QUALITY

4.8.1 User Input, Computer Processes, Computer Output

In emergency situations, accessing a reasonable quantity of water is more important than ensuring the water is free of contamination. However, when developing a long-term solution to rural water supply, the quality of water directly impacts the health of the villagers, becoming an important factor. Currently in the Nilgiris District, most villages inadequately treat their water using inefficient random doses of chlorine for disinfection, and rarely use other treatment processes. Only in reservoirs with high turbidity and chemical contamination are treatment practices like filtration and sedimentation implemented, which still do not properly rid the water of chemical contaminants. The perpetual problem of treating water in the Nilgiris District exists for two reasons: the government does not have the technical or economic capacity to treat all forms of water; and there is no organizational structure for assessing the need for treatment. Water sources should not be developed if known conditions exist that make it difficult to obtain an adequate level of quality. The purpose of Module 6 is to establish the processes required to adequately treat every potential water source for a village, and to determine whether they are economically and technically feasible.

After entering into the Module 6 worksheet, the user must input two parameters to complete the module. Similar to Modules 1 through 5, a weight is assigned to the water quality criteria signifying its importance amongst the other five criteria. Secondly, the user must assign a score to each potential water source based on the feasibility of properly treating the water. There are two methods for assigning scores to each source: qualitatively assessing the need for water treatment based on a list of physical conditions; or quantitatively measuring the important water quality parameters. The most accurate method is identifying the presence of physical, microbiological, and chemical contaminants using standard measuring tests. Once the water constituents are known, appropriate treatment processes can be implemented. Unfortunately, the government institutions do not have the technical ability or equipment to detect contaminants in the water. As such, the quantitative analysis is placed in a separate help menu file available to organizations that may be developing a system for testing water in the Nilgiris District (Appendix F, Section 11). The help file allows the user to establish water parameters that require testing, provides a list of permissible contamination levels, and describes the available processes for treating each form of contamination. Methods for testing microbiological contamination in the form of E.Coli, and physical contamination in the form of turbidity are outlined accordingly to methods used in WHO (1993b).

Since equipment is not readily available to test water parameters, the simplified qualitative approach is used on the Module 6 worksheet to assess the need for water treatment processes. The method is structured in a series of forms that are accessible from the Module 6 worksheet through a network of links that represent each source. Each form lists the potential treatment processes for the respective source, and describes a number of conditions that must be satisfied (Table 27). To effectively establish a set of required treatment processes, the user must conduct site-specific fieldwork to determine the conditions that apply to each source. Figure 28 illustrates the form used for the spring source.

There are three classifications of contamination found in water including physical, microbiological, and chemical. Standard rural treatment practices such as sedimentation, filtration, disinfection, and aeration help reduce the levels of physical and microbiological contaminants to within acceptable limits. Microbiological contamination poses the greatest risk to human health created by human and animal waste from latrines, septic tanks, and farm manure (WHO, 1993b). Physical contaminants such as turbidity, colour, taste, and odour, do not typically pose a threat to human health, but affect the aesthetics of the water supply. It is important to understand the local villagers' perceptions towards water aesthetics since in a worse case scenario they may choose to drink from an unsafe source over a noticeably unpleasant but safe source (WHO, 1993b). Since the microbiological and physical pollutants can be treated through standard methods, they are listed directly on the water source forms.

Table 27: Conditions for requiring water treatment processes

SOURCE	TREATMENT	CONDITIONS FOR REQUIRING TREATMENT
RWH	Slow-sand filtration	• rooftop is not regularly cleaned **OR** • there is no first flush system to transfer the initial dirty water away from the storage unit after a dry period
	Disinfection	• water in storage unit is exposed to sunlight **OR** • rooftop is susceptible to animal excrement and leaves **OR** • rooftop is not regularly cleaned
Check Dam	Sedimentation	• the watershed area draining into the check dam has very little vegetative cover causing high levels of soil erosion **OR** • animal husbandry is practiced extensively in the watershed area causing high levels of microbiological contamination
	Slow-sand filtration	• if sedimentation is required **OR** • the watershed area draining into the check dam has a combination of vegetative cover and exposed soil causing a moderate level of erosion **OR** • animal husbandry is practiced extensively in the watershed area causing high levels of microbiological contamination
	Disinfection	• the reservoir area is susceptible to small levels of micro-biological contamination from human and animal excreta
Reservoir	Sedimentation	• always required for reservoirs in the Nilgiris District
	Slow-sand filtration	• always required for reservoirs in the Nilgiris District
	Aeration	• if the colour, odour, or taste of the water is unacceptable to the local population
	Disinfection	• always required for reservoirs in the Nilgiris District
Spring	Slow-sand filtration	• the slopes of the spring pond do not have vegetative cover
	Disinfection	• the spring is unprotected (no surface ditch or fence) **OR** • animal or human excrement is located on higher adjacent land
Well	Slow-sand filtration	• nearby wells yield water with high turbidity
	Disinfection	• the well is unprotected (no well cover or fence) **OR** • animal or human excrement is located on higher adjacent land

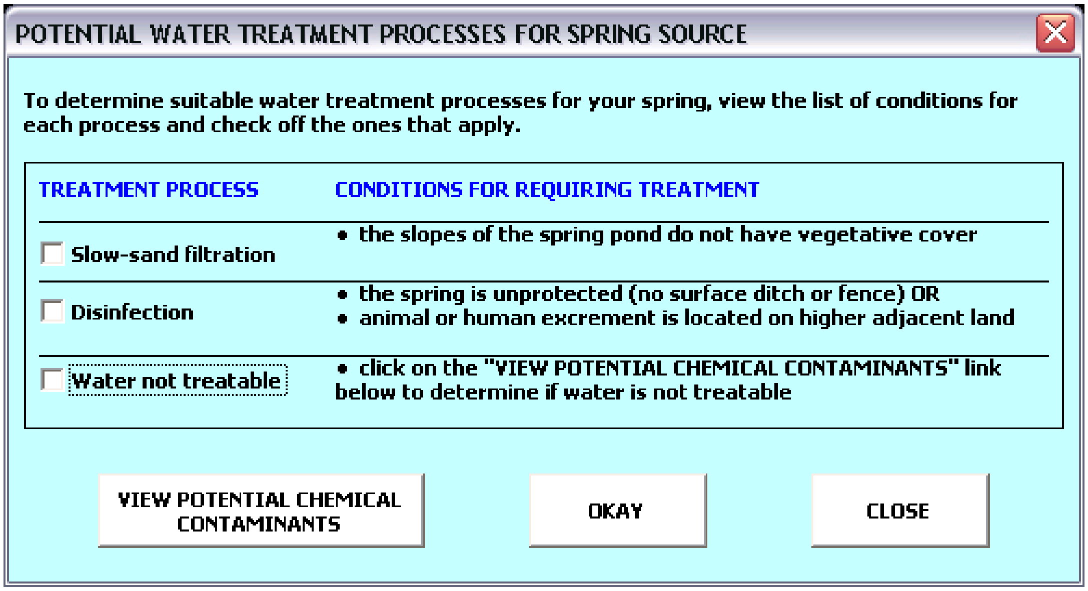

Figure 28: User form to assess required treatment processes for spring source

Treating water with a high level of chemical contamination is more involved and requires technology that is not available in the Nilgiris District. Local industries and agricultural farmers that do not practice organic techniques are the main source of chemical contamination. If groundwater or springs are being used, deposits of certain minerals also contribute to chemically polluted water. Depending on the quantity and type of chemical in the water, severe long term health effects could arise with lack of proper treatment. Since a qualitative technique for locating mineral deposits is not available, Module 6 sets up a framework for assessing the local industries and agriculture production methods. As shown in Figure 28, if a water source is observed to be chemically polluted by an upstream industry or agricultural practice, the source is declared as untreatable through current local treatment practices. A link is available on this form labelled 'View Potential Chemical Contaminants' to equip the user with information to gauge this problem. Assessing the potential for chemical contamination is carried out separately for local industries and agricultural production.

The methodology used to assess industrial chemical contamination is providing a map of the Nilgiris District which locates and describes local industries (Figure 29). Numbers on the map represent the location of all major industries and towns in the district that are likely to release chemicals into the water resources as described in the following list.

1. Company: Rallies India Ltd. - A protein processing plant that manufactures gelatine and ossein.
2. Company: Pony Needle Factory - Manufacturer of sewing needles, safety pins, suture needles, and other metal based needles.

3. Company: Cordite Factory - Manufacturer of propellants for gun ammunition which has an on-site nitrocellulose and sulphuric acid concentration plant. Solvents used in the process include acetone and ether.

4-7. Towns: [4]Coonoor, [5]Kotagiri, [6]Udagamandalam, and [7]Gulalur - Industries and activities causing chemical contamination include construction, garages, hospitals, laundry, and machine shops (House, Reed, 1997).

The cordite factory in Aruvankadu has constructed an on-site wastewater treatment plant for chemical effluent, but the level of treatment is not available to the public (Rajkumar, 2004). As such, there is a potential for chemical contamination since water quality standards are not strictly followed in India. After viewing the map to determine if a potential water source is located downstream of a particular industry, further research and investigation should be taken to understand the chemical quality of the source. If the source is believed to be chemically contaminated after investigating the industry or physically observing the water's taste, colour, or odour, the source should be listed as untreatable.

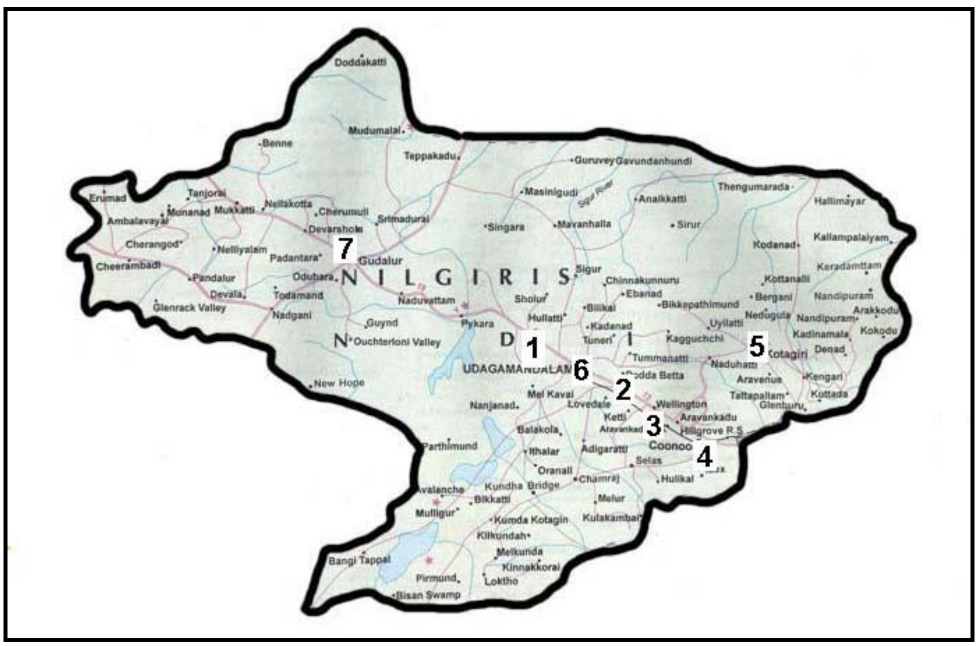

Figure 29: Map of Nilgiris District listing regions of potential chemical contamination

Farming is practiced extensively in the district with no common agricultural standards to follow. As such, Module 6 does not spatially describe the agricultural practices throughout the district, but provides a list of potential chemicals that may result from farming (House, Reed, 1997) as described in the following bullets.

- acids and alkalis
- ammonia
- arsenic (pesticides)
- cadmium (fungicides)
- copper (as pesticide)
- herbicides
- insecticides
- mercury
- nutrients (nitrates/phosphates)

The user is responsible for researching and investigating the agricultural practices used upstream of the source to determine if harmful pesticides, fungicides, herbicides, or insecticides are being used.

The presence of chemical contaminants in rainwater is rare and typically falls within Indian standards. Rainwater can be subject to bacteriological contamination through the exposed surface of a rooftop, the gathering of leaves, dust, and insects in gutters, and algae growth from storage tank exposed to sunlight (Rees, 1999). Each of these problems can be minimized by properly constructing and frequently cleaning the different components of the RWH unit. As such, there is no link on the rainwater harvesting user form for assessing potential chemical contamination.

Once the user has chosen the standard treatment processes required for a potential water source, and has clicked on the respective user form check boxes, a series of algorithms are initiated through clicking the "okay" command button. A series of 'if' statements assign a score to the source based on the guidelines presented on the Module 6 worksheet. Table 28 describes the guidelines used for assigning a score that represent the complexity and ability of the village to sustain an adequate water quality. After the source has been assigned a score, the user can change the value if local conditions are not aligned with the guidelines.

Table 28: Guideline for assessing scores for water quality criterion

SCORE	DESCRIPTION
10	• only simple source protection and disinfection required
6	• protection, assisted sedimentation or filtration, and disinfection required
3	• protection, assisted sedimentation, filtration, and disinfection required AND • additional treatment such as aeration or other
0	• very poor quality water • heavy industrial/agro-chemical pollution expected • very difficult to produce acceptable water quality using standard treatment processes

Source: House, Reed (1997)

4.8.2 Assumptions and Simplifications

Economic conditions within the district greatly influence the breadth of analysis available to the local government institutions and NGOs. A full analysis of important water parameters is ideal, but not realistic in the Nilgiris District. For this reason, the main approach to assessing water quality is simplified to qualitatively determine appropriate water treatment processes on a per site basis. The secondary method of measuring of water parameters is available in a help file, but the focus is on the qualitative approach. If at some point over time the practices of the Nilgiris District convert to a quantitative approach, NRWS would ideally adjust to the trend.

Within the qualitative structure there are three forms of contamination addressed including physical, microbiological, and chemical. One method for identifying chemical contaminants involves locating industries in the Nilgiris District that potentially release toxic chemicals into the river system. It is assumed the industries listed on the Nilgiris map (Figure 29) encompass the entire network of large industries in the district that contribute to chemical contamination of water. However, there are potentially small isolated industries that contribute to this problem. This issue is addressed in the user form through a statement that explains the need for thorough investigation into other industries.

Executing the qualitative method through a network of user forms assigns a score to each potential source based on the set of guidelines presented in the Module 6 worksheet. These guidelines have been developed in an attempt to understand the generalized perceptions of people in developing countries around the world. Even though the guidelines are useful, they may not be applicable to every situation. For the purposes of the algorithm, it is assumed that villages perceive the area of water quality according to the guidelines, however; the score can be adjusted manually if the opposite is true.

Having described the development of the six modules which together form the prototype DSS called NRWS, Chapter 5 will discuss the application of the decision support system.

5 APPLICATION OF THE DEVELOPED DSS

Without applying NRWS to villages in the Nilgiris District, it is difficult to determine if the DSS framework and associated methodologies work on a practical level and suit the local conditions. As such, a general application of the rainwater harvesting simulation was applied to houses in 10 villages throughout the Nilgiris Distract. The entire DSS was then applied to a specific case in the Emerald Valley village within the Red Hill micro-watershed. Since the conditions of the potential water sources for Emerald Valley were not fully available, a number of assumptions and generalisations are clearly described.

5.1 GENERAL APPLICATION OF THE DSS

The rooftop rainwater harvesting simulation model which exists in the framework of the DSS can also be used as a stand-alone software program. Since the simulation model contains an extensive database of daily precipitation data and requires very basic and simple data input from the user, it may be used as an effective design tool. The usefulness of the simulation model in the Nilgiris District is amplified by recent legislation that makes rainwater harvesting mandatory on every household rooftop in the state (Radhakrishna, 2003). Across the Nilgiris District, the climate and physical geography varies greatly, providing a range of rainfall conditions. As such, ten locations were tested to determine the effectiveness of using the source throughout the district.

5.1.1 Villages and house layout used for Rainwater Harvesting Simulation

There are three distinct regions that influence precipitation conditions in the Nilgiris District based on topography and monsoon patterns. Taking into consideration the presence of the three regions, 10 villages spread evenly throughout the district and encompassing all regions were used to test the rainwater harvesting simulation model. Table 29 lists the chosen villages along with their respective region, and Figure 30 shows the village locations on a map of the Nilgiris District.

Table 29: Villages used for RWH simulation

MAP NUMBER	VILLAGE	REGION
1	Pandalur	Plains
2	Mudumalai	Plains
3	Masinigudi	Plains
4	Pykara	SW Monsoon Area
5	Emerald Valley	SW Monsoon Area
6	Udagamandalam	SW Monsoon Area
7	Nandipuram	NE Monsoon Area
8	Denad	NE Monsoon Area
9	Kodanad	NE Monsoon Area
10	Uyilatti	NE Monsoon Area

The Plains region in the north sits at approximately 900 metres above sea level and is mostly influenced by the southwest monsoon period. Villages in the western part of the plains receive a significantly greater amount of precipitation than those in the eastern section due to the presence of a rain shadow. The western part of the plains is situated in the windward direction of the southwest monsoon receiving a high level of rainfall during this time period. On the other hand, the eastern section of the plains sits in the leeward direction of both monsoons creating a rain shadow that receives much less water on a yearly basis. The Nilgiris plateau which steeply rises from the plains to an elevation of 2600 metres above sea level constitutes the second and third regions that influence precipitation conditions in the district. The eastern section of the mountainous region is more strongly influenced by the northeast monsoon, whereas the western section receives a greater portion of water from the southwest monsoon.

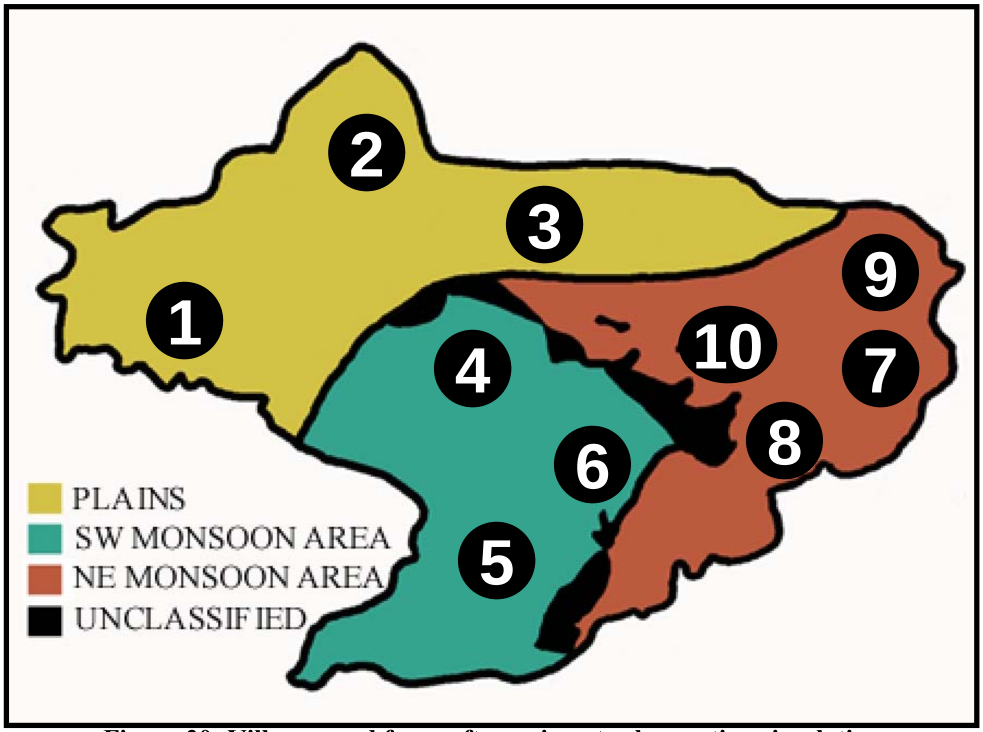

Figure 30: Villages used for rooftop rainwater harvesting simulation

The house type used to run the rainwater harvesting simulation for each of the ten villages is based on a common construction practice found in Nilgiris District and within Southern India. Starting from the foundation, reinforced concrete columns are constructed below grade to the rooftop level. Walls are then erected and a concrete slab poured on the floor. The rooftop material consists of Mangalore tiles which are distinctly unique to the region due to their bright orange colour. Since the percentage of water transferred to the storage tank directly relates to the rooftop material, it is a very important characteristic. The house dimensions are six metres by ten metres, which is typically divided into three rooms separated by curtains that consist of a sleeping area, kitchen and common room. On average, four people live in this type of dwelling and each consumes a minimum of 20 litres of water per day. Figure 31 illustrates the house type used for the simulation which has a working gutter system that is used to divert water away from the house as opposed to harvesting rainwater.

Figure 31: Typical house in the Nilgiris District

5.1.2 Rainwater Harvesting Simulation

With the house layout and villages described in the previous section, a district-wide feasibility analysis for collecting rainwater was conducted using the rainwater harvesting simulation model developed in this research. The first part of the analysis involved determining the RWH storage requirements based on known percent reliability levels. Table 30 summarises the results for each of the villages starting at a fifty percent reliability level. The percent increments decrease from ten to five starting at eighty percent in order to accurately depict the changes in storage requirements which change more rapidly at higher percent reliability levels.

Table 30: Storage requirements (in m^3) for RWH systems at different % reliability levels

MAP #	VILLAGE	OVERALL PERCENT RELIABILITY							
		50	60	70	80	85	90	95	100
1	Pandalur	0.3	1.0	3.2	7.0	8.9	**10.7**	12.6	19
2	Mudumalai	1.3	2.5	4.7	8.5	10.9	**13.2**	18.6	33.5
3	Masinigudi	0.8	1.5	2.2	4.5	6.4	**7.7**	9.6	17.5
4	Pykara	0.8	1.5	3.2	6.5	8.4	**10.2**	12.1	17
5	Emerald Valley	0.8	1.5	2.7	6.0	7.9	**9.7**	13.1	22.5
6	Udagamandalam	0.8	1.5	3.2	6.5	8.9	**11.2**	15.6	33
7	Nandipuram	0.8	1.0	2.2	4.0	4.9	**6.2**	8.6	15
8	Denad	0.8	1.5	2.2	3.5	4.9	**6.2**	8.6	14.5
9	Kodanad	0.8	1.5	3.2	6.5	8.4	**10.2**	13.1	19
10	Uyilatti	0.8	1.0	1.7	4.0	5.9	**7.2**	9.1	15

Comparing the villages throughout the district, a general pattern emerges where villages in the northeast monsoon-influenced region (villages 7,8,9,10) perform better than the other two regions since they require less storage capacity for obtaining the same percent reliability level. Rainwater harvesting units are typically designed for a 90 percent reliability level. Using this design constraint, the villages with the lowest storage requirement are Denad and Nandipuram at 6.2 m^3, whereas Mudumalai requires storage of 13.2 m^3. There are a number of reasons for differing performance levels throughout the district. First of all, it is reasonably obvious that a village which receives more precipitation will require less storage to obtain the same yield. This is true when comparing the villages of Denad and Mudumalai which receive an average yearly rainfall of approximately 1500 mm and 1000 mm respectively; however, this hypothesis does not hold true in all circumstances. The village of Pandalur receives an average rainfall of 2200 mm but requires more storage capacity than Denad. A key factor that explains this phenomenon is the dispersion of rainfall throughout the year. Pandalur, which receives the most rainfall within the chosen set of villages, has the greatest concentration of rainfall in one time period (Table 31).

Table 31: Percentage of rainfall during the three seasons of the year

MAP #	VILLAGE		SW MONSOON	NE MONSOON	DRY SEASON
1	**Pandalur**		70	20	10
2	**Mudumalai**		63	19	18
3	**Masinigudi**		47	33	20
8	**Denad**		26	49	25

Another notably important village is Masinigudi which lies at the heart of the rain shadow and has a yearly rainfall at 730 mm. Out of all the villages in the Plains and Southwest Monsoon regions, Masinigudi has the lowest level of precipitation but requires the least amount of storage to reach a 90% reliability level. With a similar trend to Denad, Table 31 shows that Masinigudi has a relatively even distribution precipitation throughout the year. This result greatly influences the argument that rainfall distribution has a greater impact on RWH performance than total yearly rainfall. One technique for analysing this argument further is evaluating the months of the year that have the greatest failure rates. Table 32 shows the monthly percent reliability levels for the same four villages, which are based on an overall reliability level of 90 percent.

Table 32: Monthly % reliability levels with an overall yearly reliability of 90%

MAP #	VILLAGE	MONTHLY PERCENT RELIABILITY											
		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	**Pandalur**	95	90	46	74	87	98	100	100	100	100	100	100
2	**Mudumalai**	97	82	56	75	84	94	100	100	100	100	100	100
3	**Masinigudi**	100	90	72	80	80	84	92	95	93	100	100	100
8	**Denad**	100	89	68	72	84	87	94	95	98	100	100	100

Even though the villages of Denad and Masinigudi have fewer months with a percent reliability of 100%, they never have a month that falls below 70%. Pandalur and Mudumalai villages on the other hand have months where the percent reliabilities fall to

46 and 56 percent respectively. These lower monthly percent reliability levels correlate with the need for more storage (Table 30) which is logical since the RWH system must be able to store enough water during the dry period to supply the household with water. Analysing the monthly percent reliability is also important for ensuring the rainwater harvesting systems do not fail on a concentrated basis. It is much easier for a household to adjust to scattered days of no water supply as opposed to an extended period without water.

A graphical representation of the relationship between percent reliability and storage is presented in Figure 32. One village from each of the mountainous monsoon-influenced regions and two villages from the plains are illustrated in the figure. A general exponential trend is found for all four villages, where Mudumalai has the highest storage requirements. The greatest change in storage occurs between the 95% and 100% interval for all four villages, indicating that reaching the entire household water needs may not outweigh the economic costs required to do so.

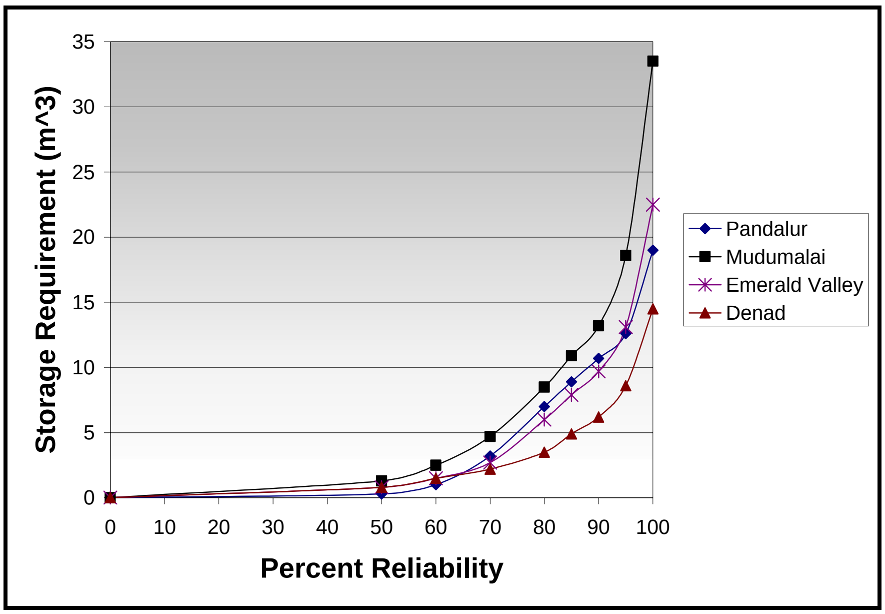

Figure 32: Graphical illustration of % reliability vs. storage for four villages

Another analysis was carried out on the highest performing village of Denad to determine the effect of rooftop area on the storage requirements for the RWH systems. Since the rooftop area used in the previous analyses was 60 m^2, small increments of five square meters were used between 50 m^2 and 70 m^2, and increments of ten above 70 m^2. Rooftop areas below 50 were not tested since they did not meet the criterion for the RWH simulation model which does not allow circumstances where the total water supply is less than total water demand. Table 33 lists the storage requirements for different combinations of rooftop area and percent reliability.

Table 33: Storage requirements (in m^3) for RWH systems in Denad village

ROOFTOP AREA (m^2)	OVERALL PERCENT RELIABILITY							
	50	60	70	80	85	90	95	100
50	0.8	1.5	2.2	4.5	5.9	7.2	9.6	15.5
55	0.8	1.5	2.2	4.0	5.4	6.7	9.1	15
60	0.8	1.5	2.2	3.5	4.9	6.2	8.6	14.5
65	0.8	1	1.7	3.5	4.4	5.7	7.6	14
70	0.8	1	1.7	3.5	4.4	5.7	7.6	14
80	0.8	1	1.7	3	3.9	5.2	7.1	13.5
90	0.8	1	1.7	3	3.9	5.2	7.1	12.5
100	0.8	1	1.7	2.5	3.4	4.7	7.1	12

Results from the analysis agree with the generally accepted and easily conceptualised rule that when the rooftop area is increased, the storage requirements decrease since a greater amount of water is entering the storage unit. More specifically, it appears the rate at which the storage requirements decrease gets smaller. Figure 33 illustrates the rate of decrease for percent reliability levels of 80, 85, 90, and 95 percent. Between the rooftop areas of 50 and 65 m^2, the storage requirements decrease relatively quickly compared to those between 65 and 100 m^2. This indicates that a point may be reached in the RWH design where increasing the rooftop area does not significantly improve the performance of the system. One possible explanation for this trend is the ability of smaller rooftops to provide adequate supply between short dry periods. In other words, there is no difference in the performance of dissimilar sized rooftops if both rooftops can collect enough water to meet the water demand during a series of dry days.

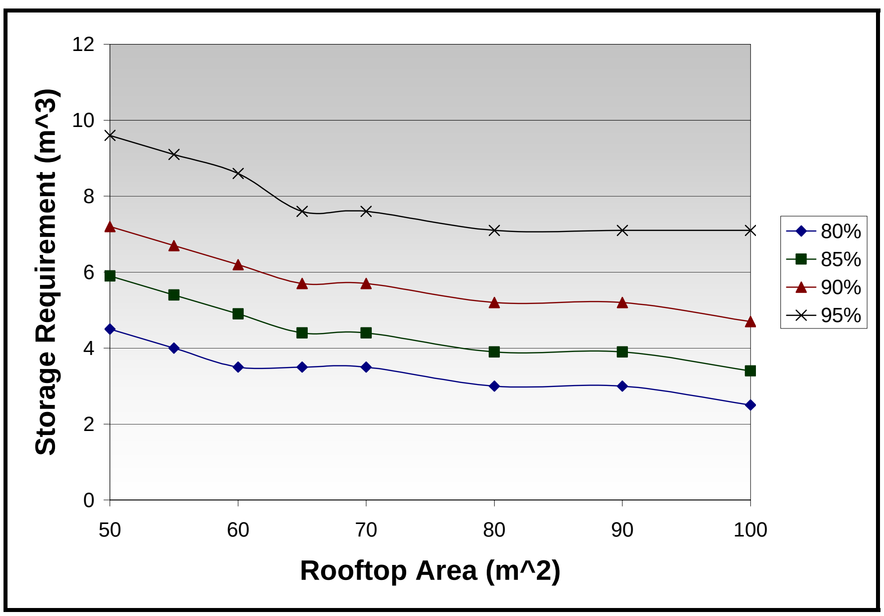

Figure 33: Illustration on the effect of rooftop area on storage requirement

One of the most important findings from the analysis of rainwater harvesting feasibility throughout the district is on the results from the village of Masinigudi. Of all the villages tested, Masinigudi is the only village located in the rain shadow of the Plains which receives the lowest amount of rainfall on a yearly basis. Villages in the Nilgiris plateau typically use check dams on mountain streams to provide water throughout the year. Villages in the western part of the plains, which receive a concentrated high level of precipitation during the southwest monsoon season, typically use shallow wells for domestic use. However, both these sources are not available in the region surrounding Masinigudi, making rainwater harvesting a valuable resource. Since the RWH units in Masinigudi have one of the lowest storage requirements compared to other villages (Table 30), implementing this source may also be economically feasible for the village.

5.2 Specific Application of the DSS: Emerald Valley Village

The Emerald macro-watershed lies in the Western Ghats on the Nilgiris Plateau and drains into the Emerald reservoir. This reservoir flows into the Kundah reservoir where it travels down the Kundah River in a south-east direction, eventually joining with the Bhavani River in the plains. This river is famous among the hill streams for its long reaches. The Emerald macro-watershed is sub-divided into six micro-watersheds, one of which is named Red Hill. The northern portion of the Red Hill watershed is heavily forested with very little human settlement except for the Emerald Valley village which is nestled in a valley between forestland and tea plantations (Figure 34). A small plot of agricultural land near the village grows vegetables for local consumption. Emerald Valley is located approximately 22 km away from Udagamandalam, the headquarters of the Nilgiris District. Table 29 and Figure 30 describe and illustrate the location of Emerald Valley within the district.

Figure 34: Layout of Emerald Valley

A total population of 473 inhabits the village, encompassing 110 families. Most men and women in the village are landless labourers who get paid the same wage, where permanent work provides 100 Rupees per day and temporary work 45-50 Rupees per day.

A tea processing plant located near the village which has been closed for three years is reopening and will hopefully provide permanent work for the villagers. The main source of energy used by the villagers is firewood which is collected from nearby forests. Scrap wood is collected on a daily basis by the women of the village.

Emerald Valley is currently experiencing water shortages during their dry season, forcing villages to consume water from nearby contaminated farm ponds. The purpose of applying NRWS to Emerald Valley is to determine the feasibility of upgrading their current supply versus tapping into a new potential water source to supplement the existing source when supply falls short.

5.2.1 Existing Water Conditions

There are three topics of equal importance that are associated with domestic water use, including water supply, sanitation, and hygiene. When undertaking a rural water supply project, it is crucial to educate the villagers on the importance of all three topics. Located in Emerald Valley is a supplementary school that was implemented through a program at RDO which provides education to children who live a great distance from the closest government school. The teachings encompass a wide range of curriculum from yoga to physical education. One component of the curriculum is hygiene and sanitation which is presented through pictures. Unfortunately there is no sanitation facility within the village which should ideally be constructed along with a new water supply system.

Water from a mountain stream two kilometres away is used as the main source for the village. A small man-made dam blocks the stream from flowing in order to create a reservoir that stores water during the dry season. Unfortunately, the dam is poorly constructed allowing a high degree of loss due to infiltration (Figure 35). The water travels by gravity through a pipeline and is stored in a 10 m^3 tank located near the village at a point of higher elevation. Since the tank has no valve to stop the flow of water once capacity is reached, water from the reservoir is constantly being drained through the storage tank overflow pipe. This practice should be remedied so that the reservoir is able to increase volume without losses at the storage tank. From the storage tank, water travels through a pipeline which feeds nine stand posts to supply the village with water. The stand posts and pipes are currently in poor condition due to leaking and require maintenance.

Figure 35: Current water supply for Emerald Valley

A comparison of current water supply to water demand is outlined in Table 34. An average family of four consumes 200 litres per day which is slightly above the Indian standard of 40 litres per person for rural villages. During the months of February to April there is a water scarcity problem which restricts the ability of Emerald Valley to obtain their ideal supply. As a result the village adjusts to the lower flow of the stream providing them with half their ideal supply. To satisfy the other half of their demand during the months of March and April, the villagers consume water from nearby farm ponds. This consumption value is not incorporated into the water deficit calculation since the source is not suitable for drinking and is only used when no alternative is available.

Table 34: Water supply and demand for Emerald Valley village

MONTH	WATER DEMAND (L/family/day)	WATER SUPPLY (L/family/day)		WATER DEFICIT
		CHECK DAM	FARM POND	
January	200	150	-	50
February	200	100	-	100
March	200	50	50	150
April	200	0	100	200
May	200	150	-	50
June	200	200	-	-
July	200	200	-	-
August	200	200	-	-
September	200	200	-	-
October	200	200	-	-
November	200	200	-	-
December	200	200	-	-

The quality of water is good throughout the year according to the villagers, however no chlorine is provided by the Panchayat (which is similar to a local municipality or county). Since the water is from a stream that is in a mountainous region with minimal upstream contaminants, the water is most likely safe to drink. However, for the two months of the dry season the villagers of Emerald Valley consume water from farm ponds which are highly contaminated due to the presence of chemical fertilizers and animal manure from runoff. Some of the villagers use cloth filtration to minimize the particulate content but the method does not effectively remove chemicals and micro-organisms from the water.

One potential improvement to the current system, suggested by the villagers, is to construct a proper check dam on the stream currently being used as the central source. This would allow more water to be stored in the reservoir for use by the village during the dry season. Besides the need for repairs to the pipes and stand posts, the existing distribution system could easily be adapted to a new check dam. Other potential sources available to the village include rainwater harvesting and the Emerald reservoir which is located two kilometres from the village. Groundwater may be a feasible option, but there is no information available on sub-grade conditions making it difficult to assess. The modules of NRWS will now be applied to the potential sources available to Emerald Valley: rainwater harvesting, check dam, and reservoir.

5.2.2 Module 1: Water Source Yield

There are three sections to be completed in Module 1 including water demand, water supply, and assigning source scores. Assessing the village water demand is the first step and involves two tasks: identifying the quantity of water required by the village throughout the year; and determining if and by how much the water demand decreases due to the continuing supply from an existing source. Using the data from Table 34, which was developed through consultation with the village, a family water demand of 200 litres per day and supply rates from the existing check dam were inputted into the Module 1 of NRWS.

In order to run the rainwater harvesting simulation model, the user must choose a location from a list of 100 villages and outline the characteristics of the village houses. Since Emerald Valley is not listed on the user form, the closest village is Ithalar which is located four kilometres away. There are three house types in Emerald Valley which all contain Mangalore tile roofing. A small portion of the houses have only one family per house, where the majority of houses consist of five families. As opposed to detached houses, these formations resemble a row of connected houses with the same structural foundation. The house dimensions and characteristics are outlined in Table 35.

Table 35: Characterics of houses in Emerald Valley

HOUSE TYPE	AREA (m^2)	ROOFTOP MATERIAL	HOUSE TYPE QUANTITY	# OF FAMILIES PER HOUSE
1	300	Mangalore Tile	20	5
2	100	Mangalore Tile	5	1
3	60	Mangalore Tile	5	1

Simulation Option 3 was first initiated to determine the relationship between percent reliability and storage requirements for House Type 1 (Figure 36). Starting at 80%, the storage requirements get exponentially larger with increased reliability. Using the standard 90% percent reliability level, which has a reasonable storage requirement of 27 m^3 for house type one, Simulation Option 2 was initiated to determine monthly percent reliability. The results showed that the months of March and April had reliability levels of 46% and 43% respectively, which coincides with the months when Emerald Valley is prone to water scarcity conditions. Since the existing check dam source provides water during the rainy season, the rainwater harvesting source is only required during the dry months, and especially during March and April when the villagers resort to using water from nearby farm ponds. Therefore the rainwater harvesting systems should not be failing to such a high degree during these months. Consequently, a higher percent reliability level was considered to improve system performance. A level of 95% with a storage requirement of 40 m^3 for House Type 1 was chosen since the increase in storage for 100% would not be feasible. The new monthly percent reliabilities indicated that only the month of April would fall below 90%, and would still obtain a reliability level above 50%.

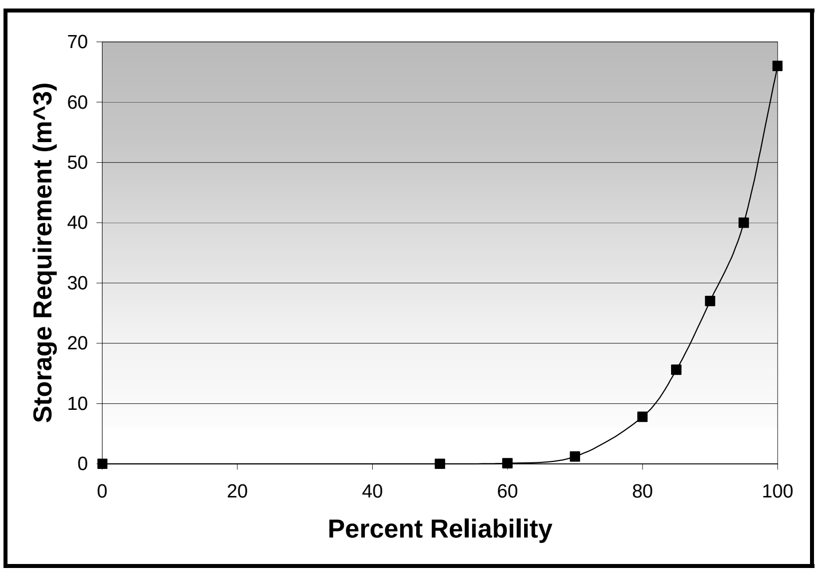

Figure 36: Comparison of percent reliability and House Type 1 storage for RWH in Emerald Valley

Obtaining an adequate supply of water from the existing check dam source involves constructing a new dam that allows more water to be stored for consumption during the dry season. Input data for the check dam simulation model was estimated using the observed site conditions and existing supply claimed by the villagers. The check dam location was visited during the rainy season and incoming flow was estimated to be ten litres per second which was used as the initial flow for the simulation. Since the recession constant requires a daily record of flow rates during a dry period which was unavailable, a recession constant of -0.04 was chosen since it matched the decrease in existing supply during the dry season obtained from the villagers. The narrow and steep location of the check dam would yield a reservoir with a maximum depth of four metres with an area of 96 metres. Using Equation 5-1 from USAID (1982), the total volume of the reservoir was found to be 155 m^3.

$$V = 0.4DA \qquad (5\text{-}1)$$

where,
V = reservoir volume (m)
D = greatest reservoir depth (m)
A = reservoir surface area (m^3)

After inputting all necessary data into the simulation, the results showed that upgrading the check dam could supply water to Emerald Village for every month except April, providing an overall percent reliability of 91%. Even though a high reliability level can be obtained, the failures are all concentrated in one time period which should be taken into consideration when comparing sources.

Emerald Reservoir is the final source being considered for implementation in the village of Emerald Valley. The large reservoir is located two kilometres from the village and must be assessed for yield based on its ability to provide enough water during the dry season when the water levels are at their lowest (Figure 37). Since RDO is currently working on the Emerald macro-watershed project, the HADP has provided a land use map for the watershed which states the total reservoir area is 304 hectares. The greatest reservoir depth is assumed to occur at the dam where the depth has been labelled as 40 metres. As shown in Figure 37, the reservoir volume during the dry season can be significantly reduced. Based on discussions with the villagers, the reservoir volume is assumed to be half full during the dry season. Using these characteristics in the reservoir sub-module, the results indicate that the village would consume a small fraction of the reservoir volume (less than 0.01%), thus having a very low impact on the reservoir.

Figure 37: Emerald reservoir during dry season

The results of the monthly reliability levels for each source sub-modules are described in Table 36, where the overall values for RWH, check dam and reservoir are 95%, 91% and 100% respectively. Since the percent reliabilities were set at a high value in order to provide the village with their ideal supply, the storage requirements are high which directly impacts system costs. This factor should be taken into consideration. Based on the guidelines presented on the Module 1 worksheet, scores of nine, eight, and ten were assigned to the RWH, check dam, and reservoir sources respectively.

Table 36: Monthly % reliability levels with an overall yearly reliability of 90%

SOURCE	MONTHLY PERCENT RELIABILITY											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RWH	100	100	96	51	93	100	100	100	100	100	100	100
Check Dam	100	100	94	0	100	100	100	100	100	100	100	100
Reservoir	100	100	100	100	100	100	100	100	100	100	100	100

5.2.3 Module 2: Capital Cost

Within the Red Hill micro-watershed management project, the HADP has sanctioned three lakh (equivalent to 300,000 Rupees) for use in Emerald Valley. The purpose of this funding is not solely for rural water supply, but for infrastructure the community collectively agrees will benefit the village most. As such, there is no specific budget for rural water supply, but this amount provides a general starting point for determining cost feasibility of potential sources.

Capital costs for rainwater harvesting are developed first as described in Table 37. There are four different storage materials available including concrete, brick/stone masonry, ferrocement, and plastic, each with a range of feasible storage capacities. Recalling that the RHW simulation in Module 1 produced an average storage requirement of 29.5 m^3 for the 30 houses in the village, the brick/stone masonry storage tank was chosen since its ideal storage capacity ranges from 15-50 m^3. Gutters are required on each house structure in order to capture water from the rooftop. Since there are no gutter systems currently constructed on the village houses, a total length of 1400 metres is required. House type one requires gutters along both 30 metre lengths, whereas house type two and three require gutters along the 10 metre lengths. A standard water filter is used on rainwater harvesting units in the Nilgiris District which makes up a small portion of the overall cost (Sahu, 2002). As shown in Table 37, water storage contributes to approximately 90% of the cost, making it an important design characteristic.

Table 37: Capital cost for RWH source

WORK/MATERIAL	UNIT	UNIT COST (Rs.)	# OF UNITS	AMOUNT (Lakh)
Brick/stone masonry storage tanks	tank	1,18,000	30	35.437
Gutters	m	300	1400	4.2
Down Pipe & First Flush Pipe with Gate Valve 5m	No.	750	30	0.225
Small slow sand filter	No.	30	30	0.135

Since the existing infrastructure of the check dam source provides adequate piping, storage, and distribution, the only associated cost is the construction of a new check dam. A past project carried out by Myrada Organization in the Nallur watershed of the Nilgiris District constructed a similar check dam for rural water supply. As such, the design specifications used in the Agricultural Engineering Department (2004) report for the Nallur watershed were used to outline the check dam for Emerald Valley. The complete design and costing specifications are outlined in Table 38.

Table 38: Capital Cost for check dam source

WORK/MATERIAL	UNIT	UNIT COST (Rs.)	# OF UNITS	AMOUNT (Lakh)
Earth work excavation and depositing (Single Rate)	m^3	23	80.07	0.019
Earth work excavation and depositing (Double Rate)	m^3	46	144.79	0.067
Concrete broken stone 40mm size in Cement Mortar for plain cement concrete work 1:5:10 (stone:cement:sand)	m^3	1081	5.04	0.054
Concrete broken stone 40mm size in Cement Mortar for plain cement concrete work 1:2:4 (stone:cement:sand)	m^3	1666	46.65	0.777
Random Rubble Masonry in Cement Mortar 1:5	m^3	1098	140.3	1.54
Plastering with cement mortar 1:5, 20mm thick	m^2	83	27.6	0.023

Currently there is no infrastructure connecting the Emerald reservoir to the village of Emerald Valley. Since the reservoir is located two kilometres from the village, a pipeline would have to be constructed through the forestland. As such, the unit length of pipeline would be 320 feet, where the pipeline is sold in increments of 20 feet. Transporting the water from the reservoir to a brick/masonry storage tank at an elevation above the village requires a pump since gravity flow cannot be utilised. A standard pump is incorporated into the reservoir costs along with a shed that houses the pump and maintenance equipment. The intake structure consisting of a pipeline leading to the motor shed must be secured at a water depth that will abstract the cleanest water in the reservoir. As such, a floating device ensures the pipe does not touch the bottom, and an anchor ensures the pipe does not intake water at the reservoir surface. Both these costs are included in Table 39 which outlines all the cost components for the reservoir source. The final two components include a sedimentation tank and a large slow sand filter which are essential since the reservoir most likely contains a high level of contamination.

Table 39: Capital cost for reservoir source

WORK/MATERIAL	UNIT	UNIT COST (Rs.)	# UNITS	AMOUNT (Lakh)
Brick/stone masonry storage tanks	m^3	4000	10	0.4
Anchor	No.	700	1	0.007
Floating device	No.	500	1	0.005
Drinking water pipeline, B-class (1”)	20ft	520	320	1.664
10 Hp Electric Motor	No.	40,000	1	0.4
Motor Shed (8ft X 8ft, height of 6ft)	No.	50,000	1	0.5
Sedimentation Tank (with weirs)	No.	50,000	1	0.5
Large Slow Sand Filter	No.	40,000	1	0.4

When comparing the overall costs for each potential water source in Table 40, the rainwater harvesting source is clearly not economically feasible for Emerald Valley. Using the HADP watershed management funding, the check dam source falls within the cost constraint of three lakh; however, the reservoir source is only one lakh over budget. With another funding source, the reservoir may be economically feasible. Following the guidelines described on the Module 2 worksheet, scores of one, eight, and five were assigned to the rainwater harvesting, check dam, and reservoir sources respectively.

Table 40: Total capital cost for each potential water source

WATER SOURCE	TOTAL CAPITAL COST (Lakh)
RWH	40
Check dam	2.5
Reservoir	3.9

5.2.4 Module 3: Cost and Ease of Operation and Maintenance

There are two intricately linked components that must be assessed when determining the feasibility of operating and maintaining potential water sources. Cost is important because the village must be able to internally fund the costs associated with running the water supply infrastructure since external funding is only available for the initial capital costs. Secondly, villagers must be personally willing and technically able to sustain the water supply. Ideally, the operation and maintenance activities take place close to the village for accessibility purposes, and minimize the need for equipment that requires frequent technical maintenance.

Rainwater harvesting has the least complex operation and maintenance tasks since the unit is contained within a small area requiring no pumping and distribution of water. The only costs associated with operating and maintaining the RWH system are fixing potential leaks in the pipe, replacing the five metre pipe leading to the storage unit, and replacing the flooring of the storage unit if serious leaks persist. The check dam source requires similar operation and maintenance to the RWH source, but has higher costs and is slightly more complex. This is due to the large distance of two kilometres between the village and the check dam which lowers the accessibility of fixing potential problems. Also, the higher piping requirements increase the cost of replacing and fixing the pipeline. Since the system is central to the entire village, one villager is paid an annual salary of Rs. 6,000 to operate and maintain the system, and the village gets together one day of the year to help in this cause. That day is called Shramadhan, and a cost of Rs. 15 per villager is required to fund a lunch for this event. Lastly, the reservoir source has similar costs to the check dam source, with a number of additional costs. Since the reservoir uses a pump to distribute water to the village, the associated costs are electricity and spare/replacement parts. The overall complexity of the reservoir is also heightened by the need for water treatment processes which must be consistently monitored.

Using an interest rate of 5% and a yearly contribution of Rs. 100 per household which is equivalent to one day's work, the total annual costs and willingness of the villagers to pay were calculated (Table 41). Villagers are willing to operate and maintain the rainwater harvesting units financially, but can only cover approximately half the costs of the check dam source and a quarter of the reservoir source. Through the awareness of the results, an increased contribution from villagers may be considered to maintain this vital resource. Taking into consideration the complexity and cost of operation and maintenance and following the guidelines described on the Module 3 worksheet, scores of ten, six, and two were assigned to the rainwater harvesting, check dam, and reservoir sources respectively.

Table 41: Summary of yearly costs for operation and maintenance

WATER SOURCE	TOTAL ANNUAL COSTS (Lakh) (YEARS 1-10)	TOTAL ANNUAL COSTS (Lakh) (YEARS 10-20)	AVERAGE ANNUAL COSTS (Lakh)	WILLINGNESS OF VILLAGERS TO PAY (% OF COSTS)
RWH	0.114	0.111	0.113	98
Check Dam	0.269	0.266	0.267	41
Reservoir	0.408	0.398	0.403	27

5.2.5 Modules 4/5: Impact of Development and Political/Legal Constraints

Impacts of development are identified in the effort to minimize the adverse social and environment effects of implementing the potential water sources. Table 42 qualitatively describes the positive and negative effects associated with each source. By running Module 1, a number of variables were established to help identify potential problems. The rainwater harvesting simulation produced an average storage requirement of 29.5 m^3 per house, which creates a land area of 15 m^2 if the height is two metres. Spatially, the storage units may not be able to fit into the current village layout. Next, the check dam simulation produced a reservoir size of 155 m^3. Since the land is steep and narrow surrounding the check dam, the amount of land being engulfed by the check dam reservoir is minimal. Lastly, developing the yield for the reservoir source indicated that less than 0.01% of the reservoir would be consumed by Emerald Village which has a minimal impact. After reviewing the guidelines presented on the Module 4 worksheet, scores of four, nine, and seven were assigned to the rainwater harvesting, check dam, and reservoirs sources respectively.

Table 42: Summary of social and environmental impacts for the three potential sources

SOURCE	POSITIVE IMPACTS	NEGATIVE IMPACTS
RWH	• environmental impact on surrounding water resources is negligible	• large storage tanks (average size 29.5m^3) are visually unappealing • houses are constructed close together and may not spatially permit tank size
Check Dam	• reservoir is steep and narrow which will not encroach on a large land area • no village uses the same source downstream • check dam reduces the erosive behaviour of high velocity waters	• the existing pipeline runs through forestland affecting local flora and fauna • construction of the check dam requires equipment transported through forestland
Reservoir	• potential village abstraction consumes a small fraction of the overall volume which does not restrict hydroelectric generation	• pipeline will have to be constructed through forestland disturbing the local flora and fauna

Module 5 is used to analyse whether there are political or legal circumstances that prohibit a source from being implemented. Since it was known prior to evaluating this module that all three sources were viable options that could be developed within the legal framework of the district, Module 5 was not used in the development of NRWS for Emerald Valley.

5.2.6 Module 6: Water Quality

There is a qualitative and quantitative method for determining the water treatment processes required to rid a source of contamination. Since equipment was not available to test the quantitative water parameters, the water treatment processes were chosen based on a list of physical conditions.

Sahu (2002) describes the standard water treatment practices used for rainwater harvesting units in the Nilgiris District. Since rainwater is relatively free of contamination, an extensive water treatment system is not required. However, a number of simple techniques are used to ensure contamination does not enter the storage tank. A small filter unit is installed above the storage unit which consists of different size aggregates, coconut fibre, and charcoal as illustrated in Figure 38. A first flush system is put on the down-pipe to divert the initial flow of water away from the storage unit after a dry period. Finally, the water is either boiled or chlorinated to kill unwanted bacteria that may cause disease.

The check dam is located in the middle of a forest that has no agricultural land or animal husbandry practice upstream. As such, the reservoir water is not exposed to high levels of microbiological contamination unless an extensive wildlife population inhabits the land. With regards to physical contamination, the high vegetation levels in the forest minimize erosion that cause high levels of particulate matter in the water. Since microbiological contamination directly affects human health, it would be ideal to chlorinate the water in the storage tank.

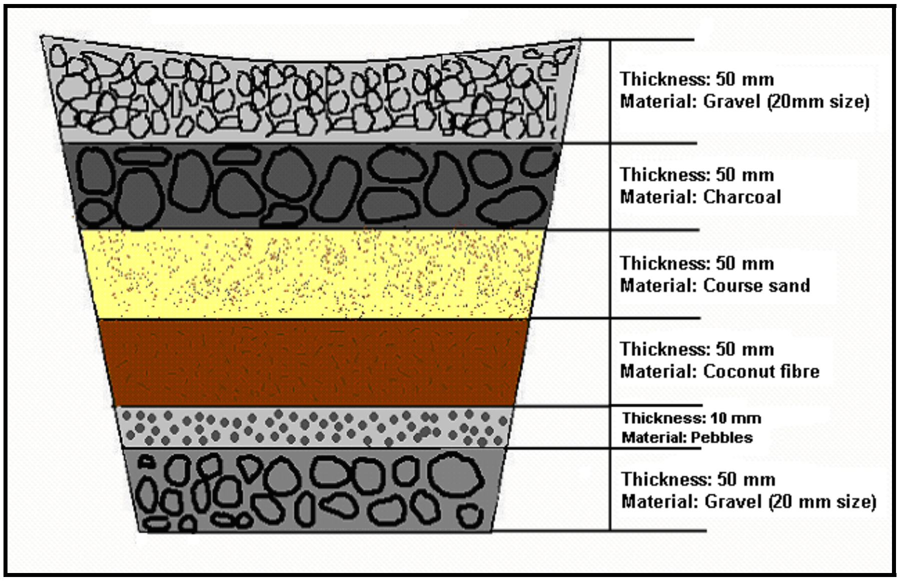

Figure 38: Bottom half of the filter unit used for rainwater harvesting

A vast network of reservoirs exists throughout the Nilgiris District to provide much of the State of Tamil Nadu with electricity. These large reservoirs gather water from large watersheds that have a wide range of land use that potentially cause contamination. Six villages lie within the boundaries of the Emerald watershed including Emerald Valley, Porthi, Old Attuboil, Porthy Hada, Bygadda, and Indira Nagar. With no access to proper sanitation facilities, much of the human and animal waste travels through the river system and into the reservoir. Farming is practiced extensively on one side of the reservoir with farmers who use pesticides. There is no known industry upstream of the reservoir that would chemically contaminate the water, but tests should be carried out to determine if the concentration of chemical pesticides is too high for consumption. Within the NRWS application for Emerald Village, it is assumed that if the standard treatment practices are implemented (including sedimentation tank, slow sand filtration, and disinfection), the water will be potable.

Using the guidelines described in the Module 6 worksheet, scores of eight, ten, and six, are assigned to the rainwater harvesting, check dam and reservoir sources respectively.

5.2.7 DSS Results for Emerald Village

Using NRWS, three potential water sources were evaluated for Emerald Valley in order to determine the most feasible source based on a list of criteria. The criteria included water source yield, capital cost, cost and ease of operation and maintenance, impact of development, and water quality. Since the village was not consulted for establishing criteria weightings, it was assumed the weightings set by House and Reed (1997) for long term supply were suitable. The only criterion that was not assigned a weighting was political/legal constraints since it didn't apply to the conditions of the village. A complete list of the weightings and scores are provided in Table 43, and an illustration of the results is provided in Figure 39. The water source that ranked the highest was the check dam source which had a score fifty points higher than the other two sources which ranked equally.

Table 43: Results breakdown for source scores and criteria weighting

CRITERION	OVERALL WEIGHT	RWH		CHECK DAM		RESERVOIR	
		SCORE	WEIGHTED SCORE	SCORE	WEIGHTED SCORE	SCORE	WEIGHTED SCORE
Water source yield	6	9	54	8	48	10	60
Capital cost	6	1	6	8	48	5	30
Cost and ease of operation & maintenance	4	10	40	6	24	2	8
Impact of development	4	4	16	9	36	7	28
Political and legal constraints	0	0	0	0	0	0	0
Water quality	5	8	40	10	50	6	30
SCORE		**156**		**206**		**156**	
RANKING		**2**		**1**		**2**	

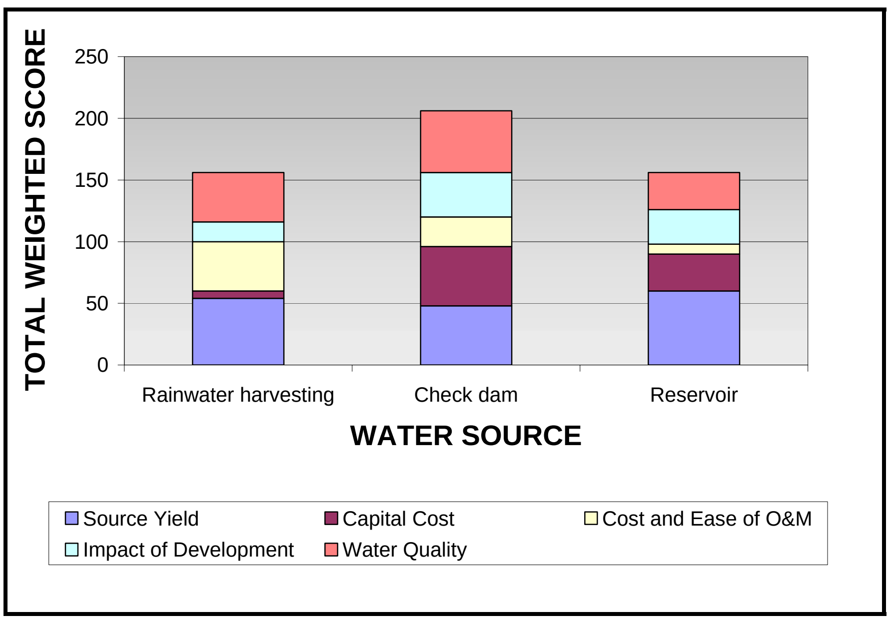

Figure 39: Results of DSS for Emerald Village in graphical format

Prior to assessing the potential sources within the framework of the DSS, the villagers suggested the most feasible plan would be to improve and upgrade the existing water supply infrastructure. The results of the DSS correlated highly with the villagers' suggestion to construct a new check dam. The most dominant factor in selecting the check dam source was the capital cost criterion.

Within this research, a conceptual model for rural water supply has been described, a prototype DSS has been developed based on the conceptual model, and the DSS has been applied to a general and specific scenario in the Nilgiris District. The general conclusions and recommendations for this prototype decision support system follow in Chapter 6.

6 CONCLUSIONS AND RECOMMENDATIONS

Countries across the world both affluent and economically deprived are treading on the brink of water crises that threaten their way of life and in some cases survival. Water has always been viewed as an abundant resource that is inherently sustainable in nature. This prevalent mentality has persisted to hinder the process of taking measures to preserve this vital resource. To make matters worse, the general consumerist attitude common in modern society creates the need for increased industrial production which pollutes the water resources on a colossal scale. It is only in the past two decades that serious thought has transformed into tangible initiatives and widespread awareness across all levels of society. Even though water is used for many purposes, the most important catalyst for change is the knowledge that humans need water to survive. Currently there are over one billion people in the world that do not have access to safe clean drinking water. Similar statistics during the 1980s prompted many world organizations to take action through large scale initiatives to improve the conditions of those most in need. Within India and Bangladesh, an extensive network of bore wells was drilled to supply drinking water to the general population since surface waters were increasingly becoming contaminated due to overpopulation and industrial production. This short term solution to masking the surface water problem did not alleviate the affliction caused by inadequate drinking water conditions. Not only did the initiative significantly deplete the groundwater resources, but also unleashed a catastrophic situation of arsenic contamination in the ground water which affected the health of over twenty-five million people (Fazal et al, 2001).

Involvement of international organizations in water resource initiatives similar to those of drilling bore wells in India and Bangladesh raises the question of the effectiveness of large-scale projects. Clearly the intentions are sincere but the actions are based on international trends and do not address the long-term locally based social and environmental consequences. Another problem associated with this approach is the dependency on aid which deters the local population from taking ownership of projects. More recently there has been a paradigm shift in the approach of international development. Organizations are focusing away from funding the capital for projects, towards developing the capacity of local communities to manage their own systems. This approach has been well integrated into water resource initiatives in the Nilgiris District of South India. The district has been delineated into separate watershed areas that each drain into one outlet point. The governing body responsible for the projects is the HADP which has allocated funds based on the spatial area of each watershed. The purpose of the watershed management projects is to assess the interrelations of human impacts on the entire water cycle as opposed to working on narrowly focussed and isolated projects. Village water associations are formed for every project so that the local populations take ownership of the infrastructure developed through the projects. All relevant government departments are involved including the Agricultural Engineering Department, Horticulture Department, Forest Department, and the Animal Husbandry Department. Many of the initiatives are implemented on the vast agricultural lands since the inadequate farming practices used in the district have negative impacts on the water resources. As well, initiatives are taken within the villages to improve the social status of villagers including enhanced rural water supply schemes.

HADP watershed management projects are ideal in theory but often lack effective planning techniques to ensure that suitable courses of action are implemented. Standardised and generic solutions are implemented which simplify the decision-making and design process, but impede the success rate of project works and activities. This is particularly true for rural water supply schemes and often leads to insufficient source yield during the dry season and infrastructure malfunctions due to the lack of technical and economic capacity within the village. A new approach to decision making for rural water supply projects would greatly help in the effort to provide every villager in the Nilgiris District with a clean and abundant supply of water for domestic use. On a global scale, many decision support systems have been developed for application in a range of situations. These generalized DSS are useful if the factors affecting the system are standardised across the world. However, this is typically not the case where a multitude of diverse systems of hydrologic, technical, socio-economic, and cultural differences exist. As such, site-specific DSS are more appropriate to deal with unique systems.

6.1 CONCLUSIONS FROM THIS RESEARCH

The developed prototype decision support system called NRWS was designed to be applicable to the conditions of the Nilgiris District. Local information was utilised and incorporated into the program algorithms in order to develop a software program that could be used by an individual with little technical knowledge. Such local information included hydrologic data, costing information, design techniques, and industrial practices. Also, many potential sources can be used in rural water supply schemes but only five were integrated into the DSS due to their popularity within the district including: rooftop rainwater harvesting, check dams, reservoirs, springs, and dug wells. The structure of the DSS was separated into six modules which represent the criteria used to evaluate potential water sources, including: water source yield, capital cost, cost and ease of operation and maintenance, impacts of development, political/legal constraints, and water quality. It is crucial for the users of NRWS to be well integrated into the communities for which the program is being applied to. As such, the value systems and perceptions of the villagers can be expressed within the structure of the DSS. If planners are assuming they have the ability to completely structure a rural water supply scheme, the project is bound to fail. Within the HADP projects, it is the role of the NGO to communicate with the villagers and to form village associations. Consequently, the NGO acts as a natural link between the villagers and government organizations, and would thus be an ideal user of NRWS.

Due to the popularity of rainwater harvesting on individual houses in the Nilgiris District, a stand-alone software program was developed for the rainwater harvesting simulation of Module 1. Design specifications such as percent reliability and storage requirements are developed, allowing individual home owners to effectively size their RWH systems. This rainwater harvesting simulation was applied to ten villages across the district and the entire DSS was applied to the Emerald Valley village in the Red Hill micro-watershed. By using appropriate weightings for the criteria in Modules 1 through 6 and assigning suitable source scores, the check dam source was found to be the most feasible source for the Emerald Valley village. A summary of the main findings from the DSS development and applications are discussed in the following sections for precipitation data, check dam model, and Modules 1 through 6.

- ***Precipitation Data***

An extensive database of precipitation data was developed for the Nilgiris District, including twenty-three rain gauge stations spread evenly across the district. Four of the twenty-three rain gauge stations were deemed unreliable due to inadequate monitoring staff. Using the historical data from a rain gauge station that had 45 years of monthly precipitation data, tests were carried out to determine if there were trends in the data. The first test assessed the slope of the regression equations between precipitation and time to determine if precipitation had an increasing or decreasing trend. Since the upper and lower limit of the 95% confidence interval contained zero, no trend was found. Next, an ANOVA test was carried out on nine sets of data with five years of data per set. The null hypothesis was accepted since the means were the same for each dataset, indicating there was no trend.

Ranging from 700 mm of annual precipitation to 3500 mm, the rain gauge stations in the district were analysed for correlation between stations. It was found that as the distance between stations increased, the correlation did not decrease as expected. Consequently, research was carried out to determine if there were different precipitation regions within the district. It was discovered that three regions existed which were influenced to a different degree by the dominant northeast and southwest monsoon periods. As such, point precipitation data for villages throughout the district were calculated based on their location within one of the three regions.

- ***Check Dam Model***

There were four different models compared for developing streamflow data that ranged in complexity. Three conceptual rainfall-runoff models were considered including the relatively simple six parameter IHACRES model along with a regionalisation technique, the Pitman model which had already been applied to the Nilgiris District, and the IHACRES model using a disaggregation technique. The final method isolated the recession constant of baseflow during the critical dry period. A comparison of the four methods was undertaken by assessing the data requirements, time requirements, cost, and accuracy of each model. Since the first three methods required an extensive network of hydrological data which would take a long time period to develop, they were considered outside the scope of this thesis. As such, it was decided to use the dry season baseflow method for establishing streamflow during the dry season.

- ***Module 1: Water Source Yield***

Ten villages spread evenly across the district were used to test the effectiveness of supplying water to households using the rooftop rainwater harvesting source. It was found that RWH systems in the northeast monsoon-influenced region performed higher than others in terms of requiring less storage for providing the same reliability. The storage requirements in the villages of Denad and Nandipuram were less than half that for the Mudumalai village in the plains region. The reason for this difference was not so much related to the quantity of water, but the distribution of water throughout the year. Mudumalai had 63% of its yearly precipitation concentrated during the southeast monsoon period whereas Denad had only 49% concentrated in the northeast monsoon period, allowing a higher percentage during the other seasons. One important discovery was that the village of Masinigudi which lies in a rain shadow and receives the lowest level of annual rainfall in the district, performed similarly to Denad. Since the region surrounding Masinigudi is deprived of water sources such as mountain streams and dug wells, rainwater harvesting may be a feasible and economically viable solution. A sensitivity analysis was also carried out to determine the effect of different rooftop areas on RWH performance. It was discovered that the storage requirements decreased with larger rooftop areas, but only to a certain point at which time the storage requirements remained constant. Therefore, the rooftop area should never go beyond this limit when developing design specifications.

Next, the entire DSS was applied to the Emerald village within the Red Hill micro-watershed. Being nestled in the valley of a mountainous region with the land use consisting of mostly forests, Emerald Valley has numerous options available for rural water supply. Three water sources were considered for testing within the NRWS framework including rainwater harvesting, check dam, and reservoir. A mathematically based procedure was executed for each source to determine potential water yield and establish key design characteristics that would influence cost.

For the rainwater harvesting simulation there were two possible approaches to take: entering a specified percent reliability and calculating the required storage; or entering the spatial availability of storage throughout the village and determining the reliability at which the storage performs. Since the villagers stressed the need for obtaining water during the dry season, the first option was chosen. At a 95% reliability level, the average storage requirement was 40 m^3 for a typical village housing unit with dimensions of 30X10 metres. The check dam source used the second option of entering a known reservoir volume and determining the reliability of supplying the village with their ideal demand. Since the check dam reservoir was using the existing water supply infrastructure, the site topography permitted a predefined space for upgrading the check dam system. Based on a site analysis, it was estimated that a maximum reservoir volume of 155 m^3 could transfer water through a pipeline into a 10 m^3 storage tank which would be used to distribute water to the village. Running a check dam simulation on these design parameters yielded a percent reliability of 91%, which failed mostly during the month of April. Calculating the percent yield for the large hydroelectric reservoir source involved the reservoir volume being adequate or inadequate as opposed to calculating an exact figure. This approach calculated whether or not the reservoir could supply the village with a six-month demand assuming no recharge to the reservoir. It was determined that the village would use less than 0.01% of the reservoir volume, minimizing the impact and providing 100% of the village's demand. After assessing all three potential water sources it was found that the reservoir source would provide the highest yield; however, all three sources performed to an acceptable level.

- ***Module 2: Capital Cost***

Based on the storage design requirements developed in Module 1 and costing data from previous projects in the district, the capital cost of each potential water source was developed. Working within the budget constraints of the HADP watershed management project, three lakh were available for improving the village infrastructure. Assuming this funding was reliable, the only source that fell within this constraint was the check dam by 0.5 lakh. The reservoir source was approximately one lakh over budget while the rainwater harvesting source was 37 lakh over budget. If funding is available from within the village or other external funding agencies, the reservoir source may be economically feasible, but the rainwater harvesting source was clearly not within budget. The contributing cost factor for the rainwater harvesting source was storage, which was 90% of the total costs. Materials for constructing a check dam and a two kilometre pipeline were the major contributing costs for the check dam and reservoir sources respectively.

- ***Module 3: Cost and Ease of Operation and Maintenance***

Operation and maintenance costs were established for each potential water source based on a twenty year infrastructure lifespan using a five percent interest rate. An assumption was made that each household in the village would be willing to contribute one day's salary of 100 rupees to operate and maintain the water infrastructure. After developing the associated costs for each source, the villagers were willing to cover 100% of the operation and maintenance costs for the rainwater harvesting source, but were only willing to contribute approximately 50% and 25% to the check dam and reservoir sources respectively. A similar trend existed for the technical complexity of operating and maintaining the water supply infrastructure. The rainwater harvesting source utilised gravity within a small-scale system creating a relatively simple operation. On the opposite end, the reservoir source required a higher technical capacity and frequent maintenance due to a pumping system, a lengthy pipeline, and a relatively complex water treatment system.

- ***Module 4/5: Impact of Development and Political/Legal Constraints***

A list of conditions for potential negative impacts was reviewed through the Module 4 help file and compiled for each potential water source. As well, three design characteristics were transferred from Module 1 to help better assess the impacts of development. The average storage requirement per House Type 1 for the rainwater harvesting source was found to be 40 m^3, and if integrated into the spatial layout of the village would obstruct pathways and not be aesthetically pleasing. Constructing a new check dam on the existing site was found to have a low impact since the 155 m^3 reservoir is situated in a narrow and steep setting. Lastly, the impact of potentially disrupting the hydroelectric production from the large reservoir was minimal since the village was consuming less than 0.01% of the dry season reservoir volume. Overall, it was found that the check dam source had the lowest social and environmental impacts since the infrastructure already existed.

Prior to evaluating Module 5, it was established there were no political or legal constraints restricting the ability to develop the potential sources. Module 5 was therefore not taken into consideration for Emerald Valley.

- ***Module 6: Water Quality***

Determining the processes required to bring water to a potable level was analysed for each potential water source. It was found that the check dam source situated in a mountain stream with little human or animal activity upstream required only a process for disinfecting the water in the storage tank. The large reservoir on the other hand was heavily polluted due to human waste from villages and agricultural runoff requiring all standard water treatment processes. The district-wide technique for treating rainwater was applied including a small filter, a first flush system, and disinfection through boiling or chlorination. Overall, the check dam source was found to be the least contaminated.

The developed prototype decision support system represents one of the first attempts at creating a user-driven tool for rural water supply that focuses on site-specific local conditions. While the DSS helps to identify issues and concerns that would otherwise not be addressed by decision makers in the Nilgiris District, there are many areas that remain underdeveloped and represent future work in this field which are discussed in the following section.

6.2 RECOMMENDATIONS

There are a number of short term recommendations for ensuring NRWS becomes a functional program within the Nilgiris District. To demonstrate the usefulness of the DSS, its application to Emerald Valley should be further developed through minimizing the assumptions made in this research. This would involve an extended time period with frequent field visits to communicate with the villagers and to gather technical data. Becoming fully integrated into the community would allow a clear transfer of values from all members of the community and not just the village elite. Consequently, an accurate account of existing water supply and demand information and the true local importance of the six module criteria could be better established. Technically, the dug well source could be added to the list of potential sources and fully assessed using pumping tests. Source yield for the check dam simulation could be based on actual streamflow data gathered during the dry season as opposed to using an estimation technique. To validate the check dam simulation method used, the model could be calibrated and tested using observed streamflow data.

If the application proves to be successful within the HADP watershed management projects, the DSS could be incorporated into the policy structure for evaluating rural water supply schemes in the Nilgiris District. For this initiative to be sustainable there would have to be two separate training programs created. One training program would instruct NGO field staff on how to utilise the DSS functions. Since extensive technical knowledge is not required to run the DSS, the training program would focus on the logistical process of qualitatively gathering data, entering data into the program, and understanding the steps required to obtain results. The second training program would teach computer technicians to upgrade the DSS data every couple years using the VBA programming language. Rainfall data would be added to the simulation to broaden the historical dataset, and costing information would be updated since a new Standardised Schedule of Rates is printed for the district on a yearly basis.

Besides further developing the DSS application to Emerald Valley and incorporating the system into the district rural water supply policy structure, there are numerous potential methods for upgrading the actual DSS functions and algorithms. NRWS provides a unique adaptable framework that can be used for creating a more comprehensive and technically advanced system; however, many constraints impede the ability to do so. Any relevant hardware or software computer components required to execute more complex tasks should be available. Also, the technical capacity of the users should match the technical complexity of any addition to the DSS. Identifying the need to address these issues can greatly improve the acceptance and usefulness of further developments to the DSS beyond this thesis. A range of potential developments exist and are classified under two topics including: improvements to the existing DSS structure; and, additions to the DSS structure.

IMPROVEMENTS TO EXISTING DSS STRUCTURE

- The complex precipitation patterns in the district caused by the different monsoon periods and mountainous topography makes it difficult to accurately estimate point precipitation data. A GIS-supported method for monitoring areal precipitation could be developed that uses regression equations to identify physical factors that influence precipitation patterns in similar monsoon regions.
- In Module 1, the source yield for every potential water source is compared on a standardised template displaying overall and monthly percent reliabilities. There is no connectivity between sources which eliminates the possibility of finding an ideal design for a combination of sources. An optimisation program could be developed to maximise the effectiveness of an interconnected system between sources.
- Currently the rainwater harvesting simulation model evaluates the entire village as one unit and outputs the average household storage requirement. If the computing capacity of computers at NGOs in the Nilgiris District improves, a series of simulations should be run to obtain storage requirements for every house type.

- For users to transfer between and understand the DSS modules, a series of text links and instructions are used. A graphical interface of pictures and illustrations may better convey the steps required to complete each task.

ADDITIONS TO DSS STRUCTURE

- To coincide with the use of NRWS, better surveying and construction practices could be implemented within the district. A simulation model for developing the storage design for a check dam reservoir is ineffective if the check dam being constructed does not prevent water from infiltrating into the ground. A series of manuals and guides of improved design techniques could be an added component of NRWS. This effort would be a much broader initiative and would require involvement from government institutions.
- NRWS uses monthly estimates of existing water supply and demand to establish the yield required from potential new sources. A more effective process would be to keep a historical record of water-use within the village. Jal-Chitra, a rural water supply planning software program developed by the Ajit Foundation, keeps a database of daily withdrawals, performance levels, and maintenance work. This type of software program would be an effective addition to NRWS in identifying the need for a new source, and increasing the accuracy of the program algorithms.
- If NRWS is to be integrated into the local system for rural water supply, it should be translated into the Tamil language to be accessible to NGO workers who do not speak English proficiently.
- Within the HADP watershed management projects, reports are created to document the implemented works and activities. Since it is the intention to use NRWS within the scope of the watershed projects, standardised printing forms should be created that organize the results of the DSS into a template that matches the format laid out by the HADP.

The recommendations presented for future work on NRWS attempt to address a question that many theorists pose. Can the methodologies and concepts developed in this research transform into a practical tool used in the field? Incorporating a computer program into a government system that still organizes most information on paper has many drawbacks, especially when there are inherent problems within the system. The DSS developed in this research has the potential to greatly improve the decision making process but must be accompanied with a change in the internal structure of the process. On a broader scale, the concept of creating localised decision support systems for rural water supply can be extended to other regions in India. The vastly forested mountainous region of the Nilgiris has very different conditions than the northern deserts of Rajasthan; not only hydrological differences, but also social and cultural differences. Given the conclusions that were put forth in this chapter, it is believed the goal of this research has been achieved; to create an effective prototype decision support system for rural water supply in the Nilgiris District of South India.

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