Small Multi-purpose Reservoir Ensemble Planning: Innovative Methods


Abstract

People living in the arid areas experience highly variable rainfall, droughts and floods often have insecure livelihoods. Small multi-purpose reservoirs supply water for domestic use, livestock watering, small scale irrigation, fisheries, and other beneficial uses. Although reservoir ensembles store a significant quantity of water and have a significant effect on downstream flows, they have rarely been considered as systems, with synergies and tradeoffs resulting from the number and density of their structures. The Small Reservoirs Project (SRP) will develop tools to assist people working at two scales. At the basin/ensemble scale, people will be helped to maintain water related ecosystem services, the long-term sustainability of local water supplies, and adequate downstream flows as they make use of small reservoirs. At the community/household scale, they will be helped to improve food security and increase sustainable livelihoods. The SRP is developing a suite of innovative methods to gather the data to be used to develop the required tools. In this paper, a selection of the SRP’s innovative methods is presented. There are methods to measure evaporative losses from a small reservoir, to assess the health aspects of small reservoirs, to assess the impact of small reservoir ensembles on water quality, to gather water poverty and water livelihood information, and to gather and prepare hydrologic information to be used in a small reservoir ensemble model developed using WEAP. During the course of the SRP we will use these and other methods we are developing to make the tools needed to facilitate the improved management of reservoir ensembles. Small Reservoir Project (SRP) is funded by GTZ through the mechanism of the CGIAR’s Water for Food Challenge Program.

Introduction

Many people in the Limpopo, the Volta, and other basins in Africa live with variable rainfall, droughts, and floods resulting in insecure livelihoods. Small multi-purpose reservoirs have often brought about positive changes in people’s lives. They are an important source of water for many communities. They typically serve several functions. They provide water for domestic use, livestock watering, small scale irrigation, fisheries, brick making, and the largely undocumented environmental function of supporting wild life.

Although there is no comprehensive record of the numbers of small multi-purpose reservoirs, there are local inventories. For example, there are 160 reservoirs in the Upper East Region of Ghana (van de Giesen et al, 2002) there are 1500 reservoirs in Burkina Faso and 250 in Northern Cote d’Ivoire; the majority of which in both countries are in the Volta Basin (Cecchi, 1998). On the Zimbabwe side of the Limpopo Basin, it is estimated there are approximately 1000 small reservoirs (Senzanje and Chimbari, 2002; Zirebwa and Twomlow, 1999). From observation and these figures it is reasonable to conclude that in the Volta, and Limpopo Basins, thousands of small multi-purpose reservoirs have been constructed.
There are often limited options for the provision of distributed storage. Larger dams feeding canals or pressurized piped distribution networks are expensive, require sophisticated management, often come with unattractive environmental externalities, and can be prohibitively expensive i.e. beyond the donors’ willingness or the governments’ ability to pay. Groundwater could be tapped using boreholes and motorized pumps. There are many areas where groundwater is not found in sufficient quantities or is found at uneconomic depths. Even if groundwater is available and its extraction sustainable, pumping requires costly energy and the maintenance of sophisticated mechanical equipment. The supply chains and cost recovery mechanisms required to support groundwater extraction are often lacking. In many areas ensembles of small reservoirs that provide water to nearby communities are the only viable water supply option. Small reservoirs don’t require energy to operate and can be maintained with locally available labor and materials.

Reservoirs were often constructed in a series of projects funded by different agencies, at different times, with little or no coordination among the implementing partners. The implicit assumption of those funding new construction is that there are social and economic benefits that can best be achieved by building more dams. That a significant number are functioning sub-optimally and/or are falling into disrepair indicates that there is room for improvement in the planning, operation, and maintenance of small reservoirs systems. Large disparities have been found between systems in the same biophysical and economic environments. Relative Water Supply (RWS) is irrigation supply divided by the demand associated with the crops, cultural practices and irrigated area. Recent research by Joshua Faulkner revealed that the RWS of two systems within a few kilometers of each other in the Upper East Region of Ghana were very different. Neither system experienced water stress; Tanga’s RWS was 5.7 and Weega’s was 2.4. The management structure at Tanga was relaxed. The management of Weega was more formal and disciplined. Weega’s command was much more fully utilized. And the farmers at Weega realized twice the profit per unit of water consumed as the farmers at Tanga (J. Faulkner et al., in preparation). Why this is so and how the performance of these systems can be improved are some of the issues addressed by the SRP.

The small multi-purpose reservoir ensembles have rarely been considered as systems, albeit diffuse ones, with synergies and tradeoffs resulting from the number and density of their structures. In an ensemble the reservoirs are hydrologically linked by the streams that have been dammed. In arid areas, these reservoir ensembles store a significant quantity of water and have a significant effect on downstream flows (Meigh, J. 1995). Their impact on downstream flows is poorly understood and rarely considered when small reservoirs are built. The density of reservoirs constructed can have an impact on the quality of the ecosystem services provided, particularly water quality. Harmful Algal Blooms (HAB) can be used as an indicator of aquatic stress. Their presence reveals dysfunction generally attributed excessive nutrient loading or pollution. It is argued that, in the context of elevated population densities, the anthropogenic pressure exerted both on watersheds and on the reservoirs themselves will enhance the probability of HAB occurrences (Chorus I., Bartram J., 1999). In addition, the impact of small multipurpose dams on people’s health is largely unknown, though the overall effect of clusters of dams may be substantial (Hunter et al.,1993). The few studies on health impacts of small reservoirs have diverse outcomes, e.g. in Ethiopia, an increase in malaria transmission had been reported close to small reservoirs (Ghebreyesus et al.,1999), but in Morocco, the higher availability of water to communities in arid mountains led to better hygiene and reduction of trachoma (IWMI, unpublished data). Thus far little or no consideration has been given to the collective impact of small reservoirs on the social and economic fabric, health, or the natural environment. The further edition of a multidisciplinary synthesis relative to the small reservoirs of Ivory Coast will partially fill this gap (Cecchi P., in press). Therefore a
concerted science based effort to plan and manage small reservoirs may result in a significant improvement in the livelihoods of the communities served by these structures.

Dissatisfied with the way water was allocated and used the people in the Volta and Limpopo Basins have begun to create new more responsive water management institutions. In the Volta the two principal riparian countries are making an effort to coordinate the use of their water resources. In Ghana, legislation creating the Water Resources Commission (WRC) was passed in 1994. The commission oversees allocation of all water resources in the country. Its staff is drafting national water use regulations, conducting management studies in the Denso and White Volta watersheds to determine how the district authorities, water users, and organized civil society can collaborate to manage water. Formerly, in Burkina Faso, the Office National des Barrages was in charge of all reservoirs. Recent legislation places responsibility for water resource management with the Direction Générale de l’Inventaire des Ressources Hydraulique (DGIRH). This agency is also exploring ways to more effectively manage Burkina Faso’s water in an explicit basin framework. And supra-national agency will soon be formally implemented (Volta Basin Authority), to assume the global integrated water managements objectives shared by all the countries involved. Likewise in the Limpopo Basin water laws are currently being or have recently been reformed. Both South Africa and Zimbabwe have new water acts. These new water laws bring with them a number of new institutions, processes, and procedures that will impact upon planning and management of small reservoirs. In South Africa moves are under way to reallocate water to previously disadvantaged groups. In Zimbabwe, the recent agrarian reform means that there is going to be a shift in ownership, access to water, and responsibility for reservoir maintenance.

The SRP’s target groups of beneficiaries are 1) people who will enjoy the more appropriate and equitable allocation of water within the basin and 2) the rural communities whose livelihoods are improved by access to water. The water management institutions in Volta and Limpopo Basins are being revamped to better serve their constituencies. This state of flux presents the SRP with an opportunity to collaborate with government officials, stakeholders, and farmers who are actively looking for new solutions. Participatory, science based research rarely takes place in an environment as open to change; only rarely does it have such a good opportunity to make an impact.

At the basin/watershed level the SRP supports the planning, development, and management of small reservoir ensembles with a purpose built set of tools and procedures. Planning reservoirs at this scale limits conflicts over water, markets, and other resources and minimizes undesirable interactions among reservoirs. At this level the process should facilitate socially and ecologically desirable and sustainable allocation of water within the basin. Conflicts over water, markets, and other resources will be limited and undesirable interactions among the reservoirs minimized. People living in and near the basin who depend on the efficient use of the water in the basin will benefit. They will enjoy more abundant supplies of food and the prospect of a sustainable production system that works without compromising either the microbial and chemical quality of their environment or the global value of the aquatic ecosystems. Negotiators will be able to choose the number, size, and location of the ensembles riparian countries should develop. They will be able to make science based decisions as to how to share water across international boundaries. They will be able to optimize these systems both hydrologically and economically, exploiting the synergies and minimizing the tradeoffs that occur when there are multiple structures. People living in these basins will enjoy increased productivity of their water resources and a socially more appropriate balance between agricultural and other water uses.
At the local/community level the SRP will promote and support the use of small multi-purpose reservoirs by developing with stakeholders a set of purpose built tools and procedures for the appropriate siting, design, operation, and maintenance of the reservoirs. The process should support the healthy, productive use of small multi-purpose reservoirs for the improvement of livelihoods. People participating directly in the use of the multi-purpose reservoirs, growing irrigated crops, fishing, watering their livestock, and using water in their households will benefit from a healthy, secure water supply. Food security will improve dramatically because farmers will not be at the mercy of notoriously unreliable rainfall. Smallholder farmers’ will be able to upgrade farming practices and produce more food through the provision of larger and more reliable water supplies. Smallholders will make more money from their irrigated plots and other income generating activities. The people’s livelihoods will improve.

The SRP is an integrated project working in three of the CP benchmark basins, the Limpopo, the Sao Francisco, and the Volta, in a variety of scientific disciplines that will contribute to improved management of these systems. There are a number of issues that must be considered when planning an ensemble of reservoirs. For reasons of cost and efficiency, all of the SRP activities designed to address these issues are not taking place in each basin. As the project progresses we will develop a general approach and synthesis appropriate for general use, a global good. For now, it is apparent that different investigators and disciplines progress at different speeds. This is a midterm report. Therefore, we will report on the progress of a selection of our activities that highlight what has been accomplished without the expectation that we are presenting a comprehensive view of what has been or will be done. The new innovative methodologies described below will all contribute to the aims of the project.

**Methods**

1) Methods for measuring evaporative losses from a small reservoir

The evaporation from the free water surface of small reservoirs is in a sense the only real water loss at regional or sub-basin level from a reservoir and associated irrigation system. Even if, only at local scales, evapotranspiration associated to aquatic pests (macrophytes) could be significant. Other losses, such as seepage from the reservoir and leakage under the root zone caused by over-irrigation, will be available elsewhere through groundwater flow downstream. This prolonged feeding of the local watertable can actually be seen as an important benefit of small reservoirs. Water used by crops is water used productively and should not be seen as a loss. Direct evaporation reduces the amount of productively usable water in the basin. Small reservoirs tend to be relatively shallow and evaporative losses are therefore high per unit of water stored. In the Volta Basin, it is common to have reservoirs with surfaces in the same order of magnitude as the irrigated area. Because evaporation takes place throughout the year, it makes up a major part of the system's water balance.

Much research into water balances of small reservoirs in the USA was undertaken in between 1950 and 1970. Unfortunately, this research did not result in general rules for the calculation of reservoir evaporation. At best, a rule of thumb can be used stating that the actual evaporation ($E_A$) can be up to twice the reference evaporation ($E_0$) due to energy advection from the drier surroundings. During previous field campaigns in Ghana, it was clearly observed that on mornings during the dry season, a strong wind blew away from the center of the reservoir, whereas in the afternoon the wind was reversed. This implies that there may be a strong oasis effect that brings warm dry air from the surrounding land to the reservoir.
In the summer of 2004, instrumentation for measuring water balance components was installed. Evaporation is difficult to measure directly, but can be estimated on the basis of mass and/or energy balances for the reservoir. Evaporation is estimated from the mass balance by measuring inflow \( Q_{\text{in}} \), outflows \( Q_{\text{out}} \), changes in storage \( \Delta S \), and rainfall \( P \), all expressed in water depth per unit time, into selected reservoirs: 

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E_A = Q_{\text{in}} - Q_{\text{out}} - \Delta S + P \quad \text{(mm/d)}
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The mass balance will be used as a check on evaporation estimates derived from the energy balance.

It is difficult to make generalizations about reservoir evaporation on the basis of mass balance estimates alone because they give no insight into the cause of high reservoir evaporation, namely energy advection. The major objective of our instrumentation efforts in the second half of 2005 was to install measurement devices that would provide us with quantitative insight into reservoir evaporation. The energy balance instrumentation consists of two parts, both installed at a reservoir near the town of Zebilla in Ghana's Upper East Region. The first part consists of six automated mini-meteo stations, arranged in a star around the reservoir (Figure 1). The meteo stations serve to measure the advection of energy from the dry surrounding land towards the reservoir. The expectation is that the convergence can be estimated by measuring the increasing wind speed towards the reservoir. Together with wind speed, the stations measure humidity, temperature, net radiation, and wind direction.

The second part consists of a floating evaporation pan with auxiliary instrumentation (Figure 2). A float was constructed surrounding an evaporation pan. By partially submerging the pan in the...
reservoir, it is expected that evaporation from the pan will be similar to evaporation from the reservoir (same temperature). Much effort went into the design and construction of this device as no standard designs are available. The result is a very stable device, due to its keel, that is not overtopped by waves, due to wave absorbing ramps. A custom designed electronic Controller/Data Logger (CDL) was designed and built to keep the pan from filling with rain or emptying out through evaporation. When the water level in the pan drops below a certain height the CDL turns on a small pump that adds water from the reservoir. Similarly, if the water level rises due to rain above a certain level, a second pump takes water from the pan. A standard meteorological station was also installed on the float to help close the energy balance. Because the float may turn around its anchor chain, an electronic compass was included in the CDL so that wind direction can be recorded. In addition, net radiation is measured as are temperatures of the water at different depths. The auxiliary measurements will be used to close the energy balance of the lake while the pan itself will give actual evaporation values. Construction and installation were finished very recently and the first results are expected in early 2006.

Figure 2. Floating pan.

2) Methods to assess health aspects small reservoirs

Our health methodologies are described in the research protocol prepared in collaboration with Jean-Noel Poda and Jean-Bosco Ouedraogo at the national health research institute in Burkina Faso (IRSS). Because so little is known about actual health impacts of small dams and secondary information is hardly available, primary data collection is combined with a questionnaire-based survey. Primary information is collected in two small reservoir clusters: Koubri, south of Ouagadougou and Kaya, north of Ouagadougou. In both clusters, a primary school near one of the reservoirs is selected, as well as control schools more than 5 km away
from the nearest reservoir. Children at these four schools are studied in more detail to determine their health status. The following health indicators are measured: prevalence and incidence of malaria, urinary and intestinal schistosomiasis plus geohelminths and level of hemoglobin. The latter is an indicator for anemia, which can be caused by several of the parasites mentioned above but is also influenced by nutritional status.

At the four selected schools, participatory epidemiological surveys are carried out using a well-tested questionnaire developed by the Swiss Tropical Institute (Utzinger et al. 2000; Lengeler et al. 2002; Raso et al. 2005), adapted for Burkina Faso in an earlier study by our partners. All teachers of the schools are asked to fill it in for all their students. The questionnaire includes questions on symptoms and diseases as well as on socio-economic aspects. After the actual sampling (see below), a relationship between the results from the questionnaires and those actually measured will be established. Thereafter, the questionnaire will be applied in a larger sample of schools in the Nakambé to determine a more quantitative relationship between health status and small reservoirs. This will be the first step in the development of a community health tool.

In each school, blood, urine, and stool samples are collected from 50-100 school children between 5 and 10 years of age. For malaria, a thick blood smear is made from a finger prick, stained and examined (Hira and Behbehani 1984). A few drops of blood are collected in micro tubes for determination of the hemoglobin level. Standard 42mg Kato-Katz thick smears are prepared from the stool samples (Katz et al. 1972) and examined for eggs of geohelminths (Ascaris lumbricoides, Trichuris trichuria, and Ancylostoma duodenale) and Schistosoma mansoni. Urine samples are tested immediately for micro-haematuria using reagent strips. Later the urine samples are filtered and examined for S.haematobium ova (Plouvier et al. 1975; Tiemersma et al. 1997). All children in the four schools will be treated for schistosomiasis and geohelminths, but for malaria only the ones found positive, because of the severity of the treatment. Ethical clearance is obtained from the National Ethical Committee.

There is also an ecological study of potential vector breeding sites. Around the select schools, different types of water bodies (e.g. reservoirs, canals, drains, seepage areas, borrow pits, rain puddles) are identified and mapped. After the first inventory, a selection of water bodies is monitored monthly for mosquito larvae and snails. Sampling for Anopheles larvae is done with standard dippers (350mm), the number of dips depending on the size of the site according to Amerasinghe et al. (2001). Snails are sampled quantitatively using a drag scoop in deep water bodies whereas in shallow habitats quadrates are sampled, depending on surface and morphological variation of the sites (Laamrani et al. in preparation). Adult mosquitoes are collected with CDC light traps, installed inside and outside the houses of eight volunteer students living near the school (and reservoir). The traps are installed and sampled once a month on two consecutive nights.

3) Methods of assessing impact of small reservoir ensembles on water quality

Maintenance of desirable aquatic ecosystems properties should be one of the goals of those managing small reservoir ensembles. (Harmful) Algal Blooms have been selected as indicator of aquatic stress: their presence always reveals a dysfunction, regularly attributed to excessive nutrient loading or pollution. Cyanobacterial blooms are of particular interest because of their potentially harmful impacts. The excessive proliferation of cyanobacteria may reduce the value of services associated with reservoirs (biodiversity erosion, eutrophication, and water quality reduction). Some cyanobacterial genera may also produce harmful toxins, with potentially important sanitary impacts on water consumers.
Firstly, by superimposing maps of reservoirs and population distribution in the Burkina Faso part of the Nakambé basin, we selected areas characterized by both high densities of reservoirs and population. Two contrasted clusters of reservoirs (a northern arid versus a southern more humid) have thus been identified (see http://www.ird.bf/activites/Localisation.pdf). Field activities are conducted mainly in these two clusters where the actual impacts of reservoir density can be studied (i.e. where densities are already elevated). Field activities are mainly based on in situ and laboratory analyses of selected “hot spots” and on field evaluations done at different scales. We will comment preliminary results associated to two large scale campaigns recently completed.

In April 2004, 23 lakes and reservoirs largely scattered in different basins at the national scale were studied. Cyanobacteria were prevalent at most of the sites (see http://www.ird.bf/activites/cyano_bf.pdf). The situation was particularly significant for ecosystems located within the Nakambé Basin. Such dominance of cyanobacteria at such a scale is a real surprise and corresponds to a situation never encountered in West African reservoirs (see Arfi R. et al., 2001). Some indices (relative to zooplankton) also indicated that the global biodiversity of pelagic communities is slightly eroded at the Nakambé basin scale. These different indications may enhance the interrogations relative to water quality within the Nakambé basin. They have also oriented the pursuit of activities.

A second important field campaign was completed this year (March-April 2005). Twenty five lakes and reservoirs, distributed from the upper parts of the Nakambé Basin to its southern limit in Burkina Faso, were studied. It has been hypothesized that external factors may be responsible for the presence of the cyanobacteria, particularly because of the development of irrigated gardening around most of the reservoirs. This activity, in using intensively a lot of different xenobiotics, may generate local, but significant pollution foci with potential strong impacts on aquatic ecosystems. For each of the 25 sites, several litres of 0.2 µm filtered water were concentrated to collect dissolved material. Aliquots of the obtained solutions were applied to aquatic organisms (bacteria, phytoplankton, and zooplankton) to evaluate their potential toxicity. Preliminary results show clearly that, in some places, these solutions are highly toxic for aquatic organisms, even at low concentrations. There is no indication today relative to the origin of the observed toxicities and samples are now to be analysed. Bioassays have also been realized for commercial xenobiotics to evaluate their potential impacts: the same planktonic organisms have been used. Contrasting responses have been obtained depending both on the polluter and the target organism considered. These very preliminary results highlight the potential, but complex impact of the combinations of several xenobiotics within aquatic ecosystems (see Ma J., 2005 and Relyea R.A., 2005). In affecting selectively, the different levels of the pelagic food web, these combinations may create imbalanced conditions that may ultimately be favorable for cyanobacteria. Experiments are now to be conducted to make progress in this direction.

For 2006, another larger scale spatial survey will be organized to better understand the incredible dominance of cyanobacteria in the Nakambé Basin. This field survey will encompass a larger climatic gradient, from the upper parts of the basin in Burkina Faso to southern areas located in Ghana. This climatic gradient corresponds also with the contrasting agro-ecological features, agricultural practices, socioeconomic conditions and tenure conditions found across the Nakambe. The purpose of this survey will be to give answers to the three following questions: Is the situation specific to the Nakambé in Burkina? Does it also occur in Ghana? If not, what could be the principle differences responsible for the observed discrepancies?
At the basin scale, small reservoirs exist at both ends of a continuum from completely rural watersheds, with weak anthropogenic pressures to, urban environments with heavy pollution associated with urban runoff. However, in most cases they are in intermediate areas; their watersheds extensively used (low income) for subsistence crops (millet), but with the areas surrounding the reservoirs of intensively exploited (high income) for cash horticultural crops (vegetables). Relationships between aquatic metabolism and agricultural practices are not so easy to identify, particularly in rapidly evolving situations. To better understand these situations is the objective of our research.

4) Methods for gathering water poverty and water livelihood information

The socioeconomic study in the Brazilian SRP has two main components: 1) Preliminary baseline study of water use dynamics in the region, and 2) Socioeconomic modeling of water use in the region. Both focus on poverty alleviation and livelihood vulnerability. The purpose of the first component is three-fold: 1) to identify key water users, water uses, access to water problems with a particular focus on poor or small-scale farming communities, 2) to analyze the key factors of water poverty and livelihood constraints as related to access to water, and conflicts regarding water use, and 3) to identify and analyze the use of small reservoirs with regards to water use and livelihood opportunities and/or constraints. The second component of the research (socioeconomic modeling) uses the above data and analysis to develop a socioeconomic-livelihoods model for the Rio Preto region. The purpose of this model will be to analyze the effects of alternative water management and policies on poverty alleviation, decreased livelihoods vulnerability, and livelihood improvement.

The methods employed for the preliminary baseline study were multi-disciplinary qualitative and quantitative interviews. In August of 2005 we surveyed ten small communities, three large farms, and five water-related institutions to identify the key water uses and water conflicts in the basin. Interview methods were based on structured qualitative surveys, and combined a Water Poverty approach (Sullivan et al 2003) and livelihoods approach (Hewitt and Hope 2005). Broadly speaking, questions fell into five main categories: 1) General demographics and economics of the community or region, 2) Access to water and related problems, 3) Use and sources of water, 4) Water Quality and 5) Institutions and Water. For the socioeconomic modeling component, the aforementioned qualitative data is being combined with the Water Evaluation and Planning (WEAP) model.

Two initial results are critical for understanding basin-level water-livelihood interactions, and for future modeling/planning efforts. “Water Poverty,” as such, varies drastically in the region, with the poorest, most isolated communities being most affected. At first glance, large farmers seem to have adequate amounts of water for large-scale irrigation. Communities with small reservoirs are also able to irrigate and sell products to the market. Communities with little institutional and infrastructure support (e.g. small reservoirs, or other) are at a significant disadvantage, as they often lack clean and readily accessible water for drinking, as well as for irrigation purposes. And while few communities site water conflicts as a major problem, interviews and observation indicate differential access to water, both within communities and within the region. This suggests that “water poverty” and/or livelihood vulnerability varies accordingly.

5) Methods to gather and prepare hydrologic information to be used in a small reservoir ensemble model using WEAP
In the Rio Preto basin methods to develop the hydrologic information necessary to model an ensemble using WEAP are being developed. The first task is to map the reservoirs and estimate their storage capacity. Landsat 7 imagery is used to quantify the number and size of all reservoirs of an area greater than one ha. In this area many reservoirs were built after 2003, which is the year for which Landsat 7 imagery was available. To capture the new reservoirs and to evaluate the quality of other sensors to study water bodies, Aster and CBERS imagery is being used. CBERS is a Chinese/Brazilian satellite. CBERS images can be obtained by Embrapa for free. If it is easy to identify water bodies using CBERS images the study can easily be expanded to other areas within the São Francisco basin.

Ground truthing must be done to develop the surface area storage relationships (Liebe, 2002). The reservoirs are located using a GPS. Their areas measured, soil samples are collected, photographs are taken and a questionnaire filled out. A detailed database of the reservoirs, water, and agriculture in the region is being compiled.

It is evident that there is at least one important difference between the reservoirs in the Rio Preto basin and those in the Upper East Region of Ghana. There is much more vegetation around the reservoirs in the Rio Preto basin (see Figure 3). Due to this fact, the surface area of the reservoirs in Rio Preto basin was determined not only by walking, but also by boating around each reservoir with a handheld GPS. By doing this the reservoirs shapes and sizes were determined more precisely.

Figure 3. Typical reservoir with wooded shore
Next we will derive the storage volume equations, which will be used to refine the procedure developed by Nick van de Giesen (as reported in Schuetz, 2005) using Monte Carlo simulations to predict the hysteretic behavior of reservoir ensembles. The resulting model will be used with Stockholm Environmental Institute’s Water Evaluation and Planning System (WEAP). In addition, the socioeconomic survey information will be used to disaggregate outcomes developed by our use of WEAP to better understand the impact of the reservoirs on the livelihoods of people in the basin.

Water balances will be used to calibrate the models. To calibrate the models accurate measurement of all mass balance parameters is vital. The mass balance approach yields no information about the spatial variation of seepage and evaporation. To improve the estimates of those components it is necessary to sample points within the basin. Three small dams will be monitored in detail. Evaporation and seepage information will be developed to be used with WEAP and to calibrate the hydrological models. Divers will be used to measure water depths and parshall flumes, installed in the reservoirs spillway, will measure discharge from the reservoirs. Reservoir evaporation will be determined by means of a series of floating evaporation pans, which consist of a standard Class A pan fitted into a floating raft designed to prevent choppy water around the pan from spilling into the pan. Three Class A pans will be distributed inside the reservoir to capture spatial variations. Three PVC tanks will be put around the Class A pan, and the measurements made in the tanks correlated with those from the pans. If the correlation is robust more reservoirs can be monitored. To measure spatial variation in reservoir seepage transacts of infiltrometers will be installed in the reservoir. The infiltrometer is being constructed from a 25 cm diameter PVC pipe, varying from one to six meters long with one end beveled to assist in driving into the soil. Once in place, all infiltrometers will be filled and covered to prevent water level changes due to rainfall or evaporation and daily measurements taken. To determine basin water availability precipitation and evapotranspiration will be estimated. Also direct flow rate measurements in the main rivers during the dry and rainy season will be made. This information will be used to develop the hydrological models which will generate information to be used as input for WEAP.

Conclusion

By harmonizing the interests of individuals served by small multi-purpose reservoirs and other people living in the basin we will increase water productivity and more closely approach optimal water use. At the basin/ensemble scale, people will be able to maintain water related ecosystem services, the long-term sustainability of local water supplies, and adequate downstream flows as they make use of small reservoirs. At the community/household scale, they will be able to improve food security and increase sustainable livelihoods. To do this we will need science based information.

The SRP is developing a suite of innovative methods to gather the data and develop the information that is needed. In this paper we have presented a selection of our innovative methods. They are methods to measure evaporative losses from a small reservoir, to assess health impacts small reservoirs, to assess the impact of small reservoir ensembles on water quality, to gather water poverty and water livelihood information, and to gather and prepare hydrologic information to be used in a small reservoir ensemble model using WEAP. During the course of the SRP we will use these and other methods we are creating to develop the information needed to facilitate the improved management of reservoir ensembles with the ultimate aim of improving people’s livelihoods.
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