Pond Design and Watershed Analyses Training

Eleventh Work Plan, Water Quality and Availability Research 3 (11WQAR3)
Final Report

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Abstract

Variable rainfall distribution and terrain make surface water harvesting and storage a challenge in many developing countries. The overall goal of this study is to collect and develop information required to equip extension, nongovernmental organization (NGO) agents, contractors, and engineers for surface water development and aquaculture enterprise development in Honduras and Latin America. A pond water balance for the levee production pond enabling determination of water flow required to balance seepage, evaporation, and direct rainfall was developed in English and Spanish on the Microsoft Excel® platform. The pump-in flow rate can also be determined for reaching a volume change per month target. A second model was formulated for evaluating surface water capture by watershed and/or hillside ponds for meeting the levee pond demand. Using hillside ponds that fill by impounding a fraction of total runoff (e.g., diverting water upstream) from streams appears to have promise for meeting water needs. A systematic approach using both models to reach a sustainable water supply target emerged from this work. Both the levee pond model and the water harvest model are based on balancing inputs and outputs given monthly rainfall patterns. A simple approach to mechanical spillways preliminary design was developed. The models are adaptable to any location if key input data is available, particularly average monthly rainfall and storm frequency-duration data. The models do not address water quality issues. The software is intended for watershed sizes not larger than 500 ha and storage ponds of less than 5 ha surface area and 4 m depth due to relationship limitations and safety concerns. Coupling with other cooperative development concerns such as marketing associations provides a platform for helping groups of people in a watershed to realize further the potential of enlightened self-interest in developing common solutions to water problems.

Introduction

Honduras is a developing Central American country of approximately 11 million hectares with both Atlantic and Pacific coasts. Mountains may be as high as 2,600 meters. Rainfall varies from 600 mm to 3,400 mm annually, with the highest precipitation generally associated with higher elevations (Anon, 2001). Temperatures above 1,300 meters are usually too cool for some economically important fish species (e.g., tilapia) production. Rainfall is unevenly distributed in the elevations where fish would most likely be produced, which requires innovative schemes for water supply development. The wide diversity in elevation and rainfall, coupled with enterprise driven needs for water development and the need to make the results accessible to local producers via a suitable network of non-governmental organization representatives motivated the development of a water supply analysis suite.

The most common approach for supplying small to medium sized communities and ponds with water is the water tube-spring. For this supply, polyvinylchloride or polyethylene pipe (12 mm to 25 mm diameter) is directed down slope from a naturally occurring spring to a site, which may be a kilometer or more from the spring. Springs are prevalent in mountainous areas at altitudes below 1,300 meters. The excavated earthen levee pond is currently the most popular containment for fish production. Hillside levee ponds (excavated levee on a hillside and supplied via a diversion ditch or other means) are not widely used. Watershed ponds are not widely used because steep valleys do not readily enable suitable diversion spillways for adequate handling of high runoff rates during rainy seasons.

Social conditions in Honduras and Central America present some challenges for computer model adoption. Our observations in the region summarize the social picture in the following way:

1) Many independent operators exercising little ownership in their country, owing in part to the legacy of political strife in the region;
2) A large network of NGO organizations is working together in a nominal manner but also in competition when areas of interest overlap;
3) A growing number of citizens are committed to improving their technical skills and to becoming computer literate;
4) Many infrastructural challenges remain to be overcome, and data needed to apply modern hydrologic approaches beginning to be available; and
5) There is a budding willingness to cooperate, particularly when it is in their interest to do so (not unlike anywhere in the world), based on assessments of cooperative marketing and production of tilapia in the region.

The enlightened self-interest idea that underlies the last item represents our reason for optimism in pursuing the modeling strategy.

There are some good resources available for pond design and watershed assessment. Nath et al. (1995) present a comprehensive pondwater quality simulation model. Yoo and Boyd (1994) summarize the state-of-the-art in pond hydrology. They discussed the water balance and water supply for the levee pond in qualitative terms. Models such as CREAMS (Knisel, 1980) and ACRU (Smithers and Schulze, 1995) are examples of watershed runoff models that require extensive inputs for watershed characterization. Inputs for both these models are not readily available.

METHODS AND MATERIALS

A suite of Excel® models was developed for water supply development, levee pond water balance assessment and levee pond economics. Databases for monthly rainfall at representative locations in Honduras, Nicaragua, El Salvador, and Guatemala were developed. Models were distributed on 1.4M floppy diskettes, which required three diskettes per student. Training workshops involving approximately 100 students were held, with at least one workshop being presented in each of the above countries. The training workshops were directed to invited professionals, leading NGO personnel with interest in aquaculture, and some major producers. These workshops typically lasted for one day. Issues related to pond siting and pond construction were presented in English, with participants having printouts translated into Spanish. A translator was also providing a Spanish translation of the oral presentation. Participants sat in front of computers with English or Spanish versions of the models and learned how to use the models in the course of the instruction.

The Excel® platform was selected due to the common availability of this software. The disadvantage of distributing software via disk is that when errors are found one cannot retrieve the disks to contain the error. We thus began research the concept of a web server-based approach, which combined the catchment analyses and levee pond water balance models into a seamless process for evaluating water supply and water balance. An English version of the server package was delivered to Zamorano for installation. A Spanish version of the server package was very recently completed and delivery to Zamorano is pending.

A scoring system ranging from 1 (unsustainable pond) to 5 (sustainable pond) was developed following trends in cumulative overflows and underflows. The scoring system is described as follows:

1) The pond has a series of withdrawals greater than twice the pond volume and/or the total volume balance goes below 0.1 over the year. Slim chance of suitability. Reduce the water withdrawal and/or look for another location.
2) The pond withdrawals exceed the volume and at the same time the pond inflow exceeds two volumes of the pond over the year. Expensive for partial year service. Reduce water withdrawal. Consider a controlled diversion.
3) Same as 2 except that inflow does not exceed two pond volumes over the course of a year but does exceed the pond volume over a year. Considered useful for partial year service. Consider a controlled diversion.
4) Withdrawals do not exceed one pond volume over a year. Inflow is excessive. Consider a controlled diversion. Can be a reliable pond.
5) Represents a sustainable pond from the withdrawals and inflow perspective.

RESULTS

The performance of the models was studied using the site score. Values of the site score were determined over 3 pond sizes, 3 watershed sizes, 3 cover conditions, 2 soil (seepage) conditions and 6 locations. For evaluation purposes, low (635 mm), medium (1,600 mm) and high (2,200 mm) uniformly distributed rainfall conditions were included with location, necessitating 586 runs. A constant demand of 10 l/min was used in all runs. Selected trends in the data are shown in Figures 1–5.

Large ponds (5 ha) gave higher scores than did small ponds. Forest covers produced the lower scores due to least runoff. Large watershed areas (250 ha) increased the site score. High seepage rates decreased the site score.

Region location had a major impact on site score as shown in Figures 4 and 5. Even with a very small pond, the availability of a uniform rainfall condition would enable sustainability. The minimum depth of the pond should not be less than about 1 m to minimize vegetation establishment in the pond. The primary benefit of the large pond is that it enables storage sufficient to meet demands in dry months, given that evaporation and seepage is not excessive. One difficulty of using the large pond and large watershed is the required width of emergency spillway that invariably results with a large watershed experiencing pronounced wet and dry periods.

Most regions of Honduras have wet and dry extremes within the year. Thus, the assumption of constant base flow and constant pumping rates are not realistic. The model was modified to use monthly estimates of water demand and base flow, entered into the model on a "Programmed Input" sheet. The strategy of using a controlled impoundment (e.g., diversion) into the storage pond was also developed. One may input the fraction of the monthly flow to be diverted to the pond on this sheet. Site scores may be increased and emergency spillway widths decreased by using controlled diversions.The controlled diversion strategy is shown in schematic form for the hillside pond in Figure 6.

Coche et al. (1995) gives additional illustrations showing how the diversion approach may be used for levee ponds with direct production. An additional benefit of the diversion is the reduction in silt accumulation owing to the reduced flow.

DISCUSSION

The models are proposed as screening tools, although they can be used for more sophisticated analyses as data becomes available. The models can be adapted to any location by including appropriate monthly rainfall data and storm frequency-duration data. The models do not address water quality issues. Cautions are given not to exceed watershed sizes of 500 ha and storage ponds of 5 ha 4 m due to model limitations and safety concerns.

Water quality should be considered when collecting surface water for specific uses. Although species such as tilapia are tolerant of turbidity and nutrient concentrations, pesticides must be monitored. Knisel (1980) has extensively documented the runoff of pesticides from agricultural fields. Di Guardo et al. (1994) studied pesticide runoff in the fisheries context with the goal of estimating fugacity coefficients for several pesticides. Nath et al. (1995) have developed a model for assessing pond water quality.

Use of the spreadsheet platform enabled a highly customized tool for the country of Honduras. Technically minded people easily grasped the concepts behind both models, including the use of the goal seeker tool. The advantage for Honduras surfaced as a significant disadvantage for porting the model to surrounding countries. Using the drop-down box approach for managing rainfall distribution within the country required that specific town names be embedded in the logic throughout the model. The levee pond balance model is approximately 500K and the water harvest analyses model is approximately 1.2M in size. A free copy of each model may be obtained by contacting the author.

CONCLUSIONS

The levee pond and water harvest evaluation models are easily extended to any location with appropriate monthly rainfall and frequency-duration and evaporation data. The application was designed with aquaculture production as a goal but the applications are not restricted to aquaculture. The steps in using the levee pond balance and the water harvest supply evaluation are as follows:

1) Set a management recirculation value for pond nutrient and waste management in consultation with the fish production and/or other specialists.
2) Determine the required water supply to balance seepage and evaporation and meet the management-determined volume value.
3) Run the water harvest analyses on one or more available watersheds to determine a score. Optimize the score by considering diversion strategies. Use judgment to properly factor in the suitability of the site to accommodate the required emergency spillway.
4) Reevaluate the management target if low site scores are unavoidable (a likely outcome). Consider a production scheme that will reduce water requirements. Rerun the most promising water harvest analyses.
5) Continue the levee balance-water harvest analyses iteration until an acceptable water requirement is determined.
6) One should consult an engineer for designing the water harvest pond due to the safety implications and expense aspects given that these ponds will frequently exceed 1 ha in area and 1.5 m in depth.
7) Tag team the modeling work with other social cooperative endeavors such as marketing.

The diversion of a portion of the runoff via an impoundment factor is an important component of surface water management strategies, particularly in regions with highly seasonal rainfall and drought periods.

The equation for pipe flow hydraulics proved to be an excellent simplification of current approaches for designing mechanical pipe spillways, particularly for routine designs not exceeding the data ranges shown in Table 1. Predicted diameters were usually well within 2% and never exceeded 6% of the design diameter when head was greater than 1 m and pipe diameter was greater than 50 mm.

Limited hydrologic data availability is the main limitation in applying the model in general. Ongoing data collection efforts will ameliorate this limitation in time.

The spreadsheet (particularly, Microsoft Excel®) platform is widely available, portable, easy to follow and highly interactive. The platform can easily be adapted to include more sophisticated analyses approaches as data becomes available. The major disadvantage of the platform is that highly customized versions that include place names in drop down boxes are not readily modifiable for other locations.

ANTICIPATED BENEFITS

The levee pond software enables one to identify climates and soils where functional tilapia levee ponds are possible. The pond requires knowledge of seepage rates of soils and knowledge of how to measure water flow rates from springs or streams. The model performs a water balance given incoming stream or well flow, monthly rainfall, monthly evaporation and soil seepage. The user can select the appropriate climatic region in Honduras, input an appropriate seepage rate for the soil and input the available stream or well flow. The user can try numerous pond areas and depths to determine if the specified pond will maintain its volume through the typical year.

The catchment pond impounds water for multiple uses, one of which may be to supply a levee pond for tilapia production. The catchment pond software enables the water balance as for the levee pond. In addition to the inputs for the levee pond, the watershed pond catches all or part of the runoff from a watershed upstream. The pond evaluates the area needed to provide adequate runoff to maintain pond volume during driest month and provides analyses of sustainability through the year in the event that the watershed area will not supply adequate water during parts of the year. A rating is provided for comparing pond feasibility over multiple sites.

ACKNOWLEDGMENTS

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Figure 1. Effect of watershed cover type on site score with the 5 ha pond.

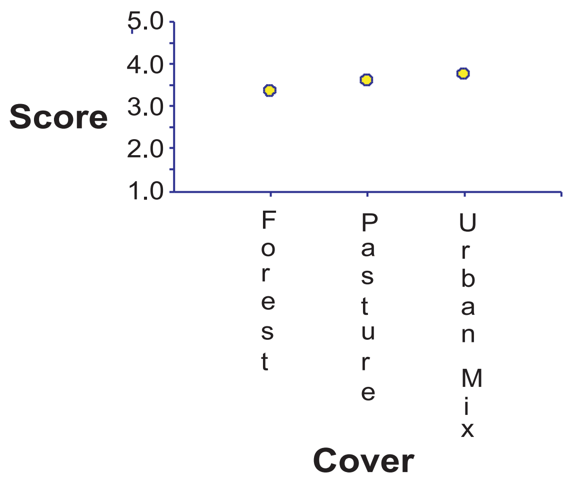


Figure 2. Affect of watershed area (ha) on the site score with the 5 ha pond.

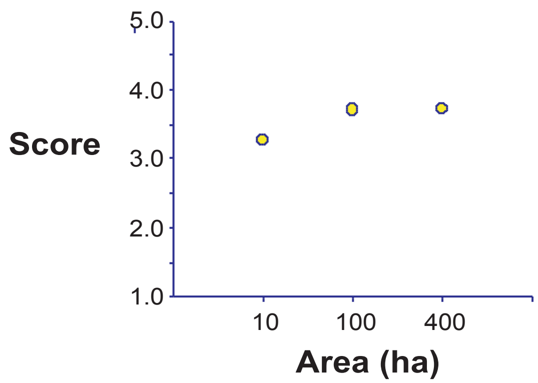


Figure 3. Affect of seepage rate on the site score for the 5 ha pond.

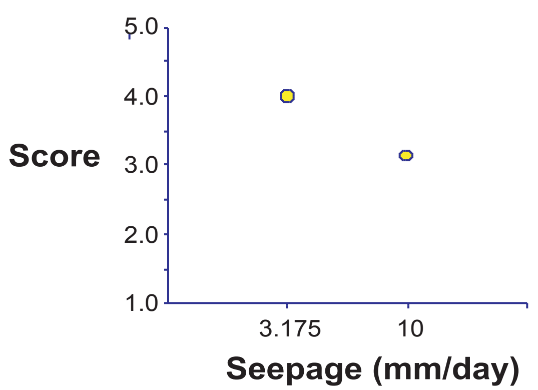


Figure 4. Site score as affected by location in Honduras with the 0.5 ha pond. The uniform distributions were used to compare the effect of uniform rainfall versus the extremely seasonal rains at Catacamas, Choluteca, Comayagua and Santa Rosa.

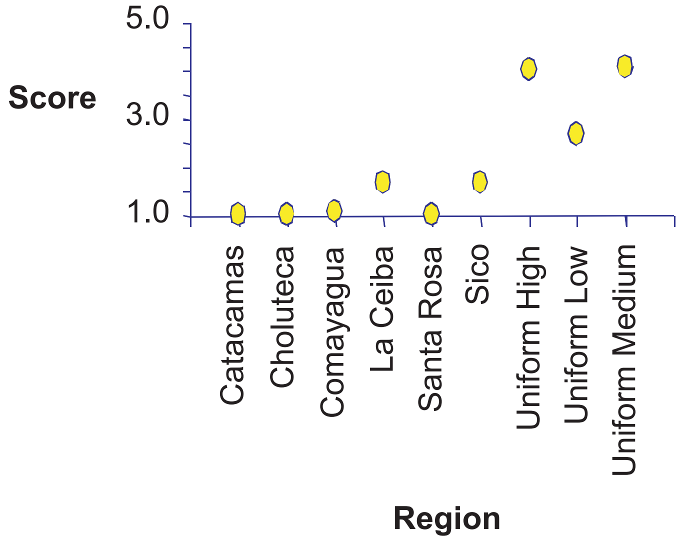


Figure 5. Site score as affected by rainfall distribution (region) and hypothetical uniform distributions for the 5 ha pond. The difference between this plot and that in Figure 4 is that the pond is 5 ha here vs. 0.5 ha in Figure 4.

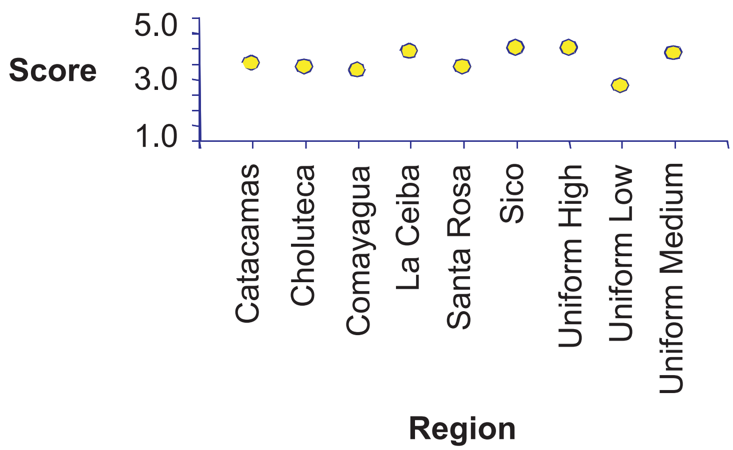
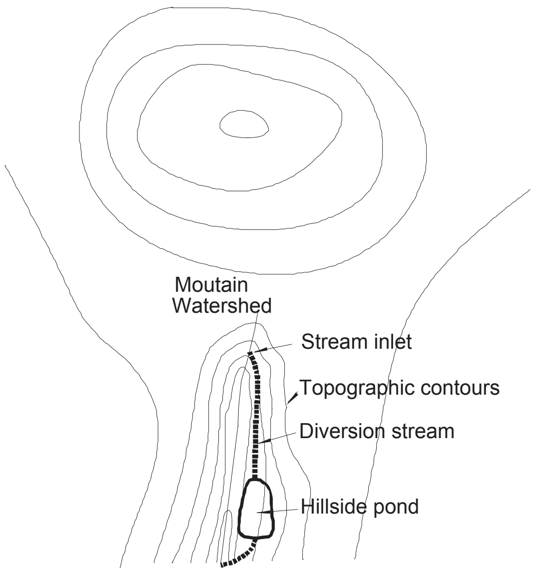


Figure 6. Hillside pond with stream diversion for general-purpose water supply. Not shown are levee ponds being supplied at a more or less constant rate from the hillside pond.



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