INSTITUTIONALIZING TECHNIQUES FOR BUILDING HILLSIDE AND LEVEE PONDS FOR WATER SUPPLY AND AQUACULTURAL DEVELOPMENT IN LATIN AMERICA

Tenth Work Plan, Adoption/Diffusion Research 1 (10ADR1)
Final Report

E. William Tollner, Brahm Verma, and Jennifer Maldonado
Biological and Agricultural Engineering
University of Georgia
Athens, Georgia, USA

Biological and Agricultural Engineering
University of Georgia, Athens, Georgia USA

Daniel E. Meyer and George Pilz
Escuela Agrícola Panamericana
Zamorano, Honduras

Joseph J. Molnar
Auburn University
Auburn, Alabama, USA

ABSTRACT

The overall goal of this study is to collect and develop information required to institutionalize pond design in Honduras and Latin America. This study is coordinated with the training activity outlined in other Honduras Project investigations. A levee pond water balance that enables the determination of how much water is required to balance seepage, evaporation, and direct rainfall was developed in English and Spanish. The pump-in flow rate can also be determined that allows ponds to reach a target volume change of water per month. A strategy based on surface water capture by watershed and/or hillside ponds for meeting the levee pond demand was also evaluated. Using hillside ponds that fill by diverting upstream water appears to have promise for meeting water needs. A systematic approach using both models to reach a sustainable water supply target was proposed, which builds on ideas of the Food and Agriculture Organization. Both the levee pond balance model and the catchment model are built around the idea of balancing inputs and outputs, given monthly rainfall patterns, and thus address rainfall distribution as well as quantity. The models do not address water quality issues. The models were built using MS Excel® as a platform. Cautions are given not to exceed watershed sizes of 500 ha and storage ponds of 5 ha due to model limitations and safety concerns.

INTRODUCTION

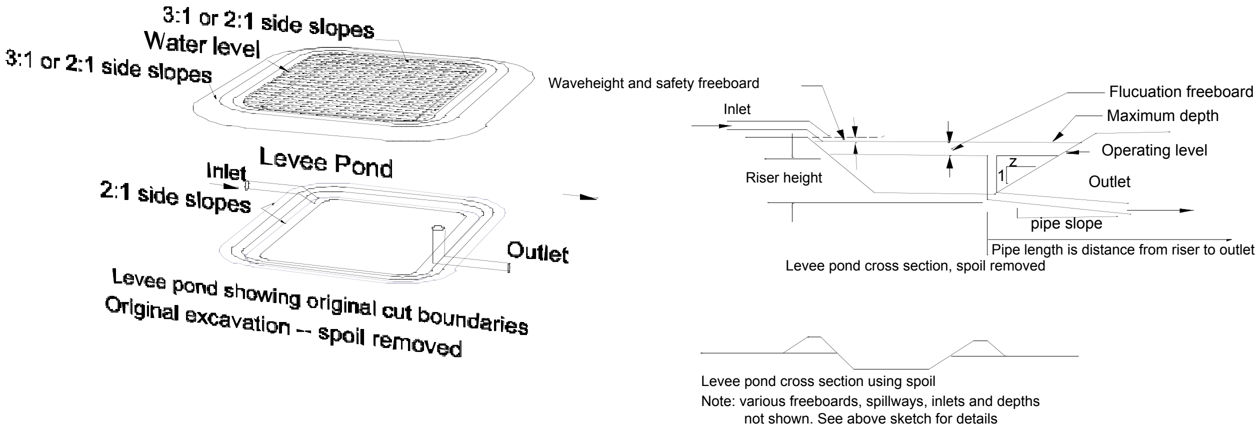
Honduras is a Central American country of approximately 11 million hectares with both Atlantic and Pacific coasts. Mountains may be as high as 2,600 m. Rainfall varies from 600 to 3,400 mm annually, with the highest precipitation generally associated with higher elevations (Anon., 2001). Temperatures above 1,300 m are usually too cool for tilapia production. Rainfall is unevenly distributed in the elevations where tilapia would most likely be produced, which requires innovative schemes for water supply development.

The current state-of-the-art approach for supplying small-to medium-sized communities with water for a variety of uses (including ponds) is the water tube-spring. PVC or polyethylene (PE) pipe (12 to 25 mm in diameter) is run downslope 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 m. The excavated levee pond (Figure 1) is currently the most popular containment for fish production. The watershed pond is not widely used because the steep valleys do not readily enable suitable diversion spillways for adequate handling of high runoff rates during rainy seasons.

The overall goal of this study is to collect and develop information required to institutionalize pond design in Honduras and Latin America. This study is coordinated with the training activity outlined in other Honduras Project investigations. Specific study objectives are to:

1) Estimate local runoff coefficients (Natural Resources Conservation Service curve number parameters, rational runoff coefficients, and soil seepage parameters) for an existing Excel® model developed for the design of hillside and watershed catchment ponds for water supply development; and

2) Develop strategies for designing and managing sustainable levee ponds for aquacultural production that reflects local conditions based on local water supply and soil suitability for pond development.



V = [LW+(L-2sd)(W-2sd)+4(L-sd)(W-sd)](d/6)

where L is length (m), W is width(m), s is the side slope factor (usually 3) and d is the (
and V is volume (meters ^3)

Figure 1. Schematic of the levee pond. The hillside pond also uses similar geometry.

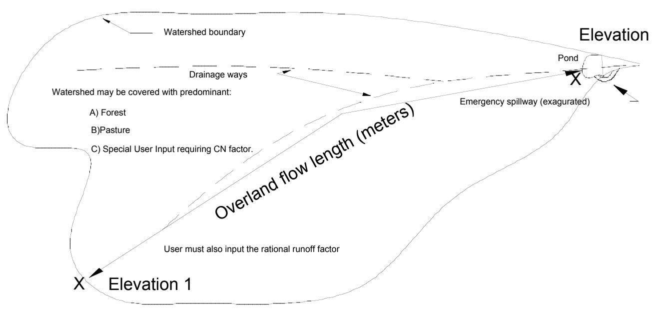


Figure 2. Schematic of watershed also showing the watershed pond.

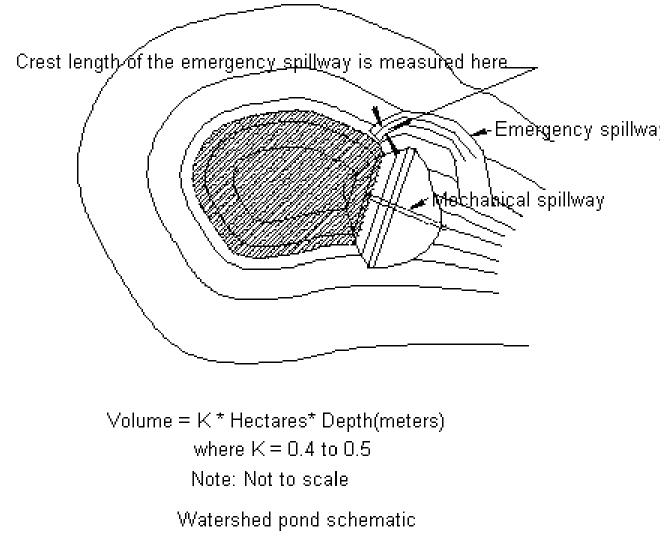


Figure 3. Plan schematic of a watershed pond.

Model Development

Levee Pond Water Balance
Water supply development and application for fish culture in Honduras began with the construction of a so-called "goal seek" Excel® model for determining the water flow required to balance seepage, evaporation, and direct rainfall demand for a levee pond on a monthly basis. This model assumes zero replacement of pond volume per month, based on outflow. The water balance is shown schematically in Tollner et al. (2001). Directions and design drawings for use are included as a worksheet and are keyed to the input fields shown on the input sheet. Drop-down boxes and data validation features were liberally used, as were comment features. The levee pond does not intercept runoff from surrounding watersheds. One may specify three pond areas-depth combinations, then select which one is of current interest. Having three choices in the model enables rapid comparisons between two pond sizes.

Once this balance value is determined, one may then determine the inflow rate required to change the pond volume at a managed frequency. The balance value plus the inflow needed to reach the replacement volume target determines the water supply need. The model reports results of monthly average, maximum, and minimum monthly balance values, along with recommended spillway pipe dimensions. The goal-seek Excel® tool is invoked to find the balance value. Goal seek is again invoked to determine the pump-in rate required to meet the volume change target plus the balance value.

Ideally, the pump-in or inflow value would be provided by a spring. However, reliable springs are becoming increasingly more difficult to locate. Thus, a strategy for developing surface water supplies that was adapted to the hilly terrain of Honduras was developed. This necessitated the development of a runoff catchment model.

Runoff Catchment Model
Given monthly rainfall and evaporation data, along with watershed cover and soils data, the catchment analysis model estimates on a monthly basis runoff, seepage, and evaporation for a hillside or watershed pond with a specified surface area and depth. A water balance similar to the levee pond balance

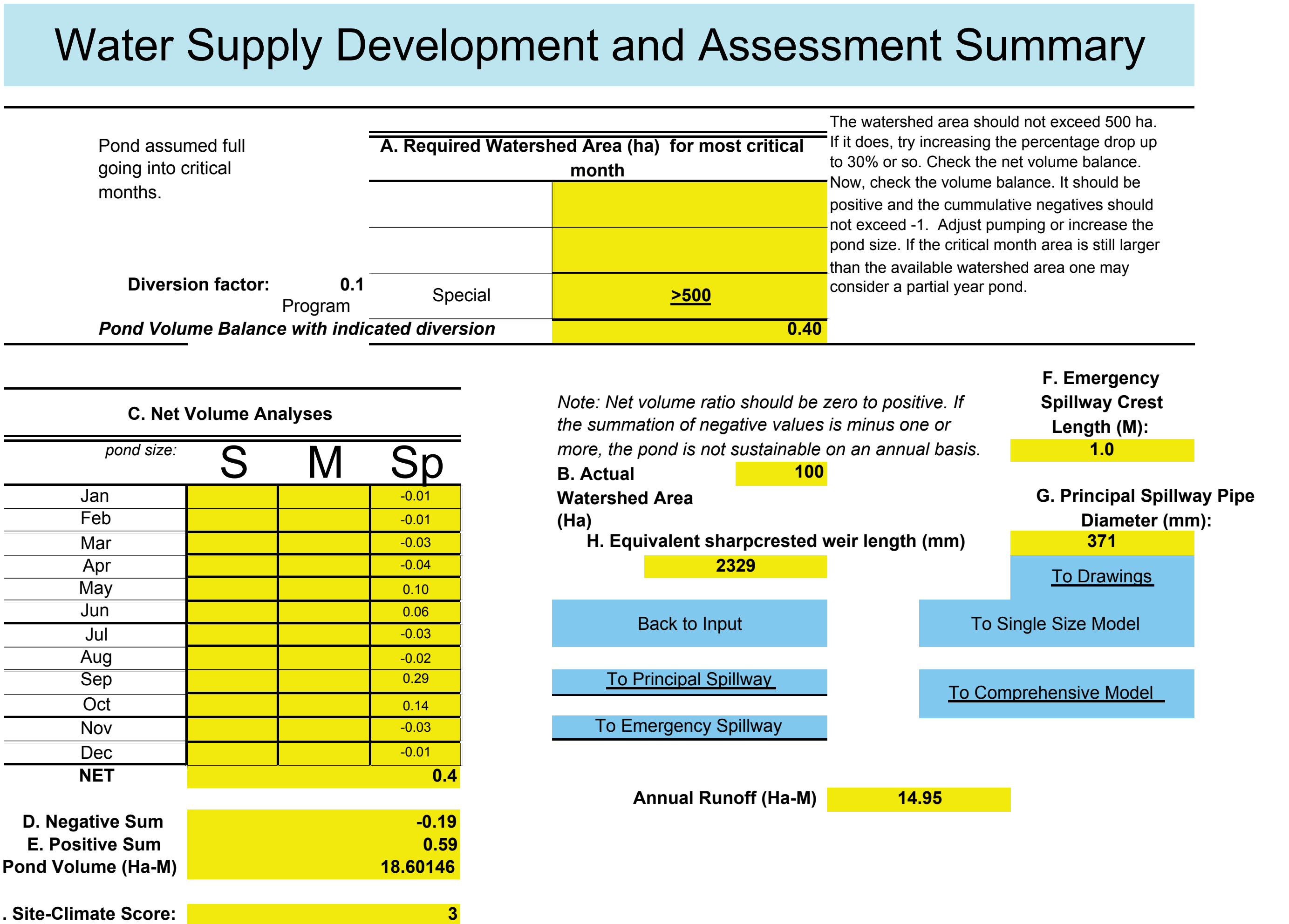


Figure 4. Output summary sheet from the catchment analyses spreadsheet model.

is used except that runoff from surrounding catchment is included, as is base flow. The fundamental difference between a watershed pond (Figures 2 and 3) and hillside pond is that the depth-volume relationship is different. Base flow, pumping demand, and the percentage of total runoff as set using a diversion control can be set to respective constants for the year or can be conveniently programmed to vary on a monthly basis throughout the year.

Annual rainfall data exists for Honduras, as does a reasonably good soils mapping (Anon, 2001). Infiltration and runoff from the watershed depends on the soil and cover in the watershed. We were able to estimate monthly rainfall distributions over six regions in Honduras.

Seepage volume from the pond is estimated by applying a daily seepage rate over the full pond area. Seepage rate may vary from zero (lined pond) to 25 mm d^{-1} (sandy), with sandy loams lying between the clay soil (3 mm d^{-1}) and loamy soils estimated to seep at 6 to 10 mm d^{-1}. For the most precise work, seepage should be estimated by digging pits at the pond site, filling them with water and assessing steady-state infiltration rates. Meyer and Meyer (2001) and Coche et al. (1995) provide an excellent practical discussion of seepage determination and other pond design aspects.

The catchment must be equipped with a principal mechanical spillway to handle routine rainfall events and non-routine intense storms. Limited data were available to estimate the two year 24 hour storms and ten year 24 hour storms over six regions in Honduras in which rainfall patterns were computed. The mechanical spillway was designed using simplified culvert analyses based on the two year storm and the emergency spillway was designed using standard weir hydraulics based on the ten year storm (Tollner, 2001). Existing hydrologic data are not sufficient for storm estimation with longer return periods. The required width of the emergency spillway is an important consideration when siting the pond.

As with the levee pond model, directions and design drawings are keyed to each input field on the model input sheet. The input sheet is somewhat more complex because one must input watershed cover, determined by using the NRCS curve numbers and runoff coefficients, described using the rational method coefficients. The model uses the US-NRCS TR-55 curve number method for monthly runoff estimation. This and related techniques are documented in Tollner (2001). Tables of curve numbers for various land covers are not available in Honduras. Therefore, estimated curve numbers for Honduran regions were determined in consultation with in-country agronomists and correlations with US data. The correlations took cover type and soil type into account. One may input three pond sizes as before, where default values are used for the small and medium sizes. The more sophisticated user may input any custom size (up to five ha and up to four m deep), with these limits being imposed by the model due to safety concerns. Similarly, small and medium watersheds (typically 50 ha and 100 ha), covered predominantly by pasture and forest, are available as default values. More sophisticated users may do more thorough analyses of curve number and runoff coefficients for the watershed. The model contains curve number tables for this purpose. A calculator sheet for computed weighted average curve numbers and runoff coefficient models is also included. These results are then manually inserted into the appropriate fields on the input sheet. The curve number method is generally limited to watersheds smaller than 500 ha. Pond sizes are suggested not to exceed five ha and four m deep due to safety concerns.

The catchment model does not use the goal-seek tool. Instead, the model computes the percentage of pond volume that overflows (positive) or underflows (negative) in the given month. Cumulative overflows and cumulative underflows are determined, as are computed principle and emergency spillway dimensions. A scoring system 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 falls below 0.1 over the year. Slim chance of suitability. Reduce the water withdrawal.
2) The pond withdrawals exceed the volume and at the same time the pond inflow exceeds twice the volume of the pond over the year. Expensive for partial year service. Reduce water withdrawal. Consider a diversion.
3) Same as 2 except that inflow does not exceed twice the pond volume over the course of a year but does exceed the pond volume over a year. Considered partially sustainable. Consider a diversion.
4) Withdrawals do not exceed the pond volume over a year. Inflow is excessive, requiring a diversion. Can be a reliable pond.
5) A sustainable pond from the withdrawals and inflow perspective.

The dimension of the emergency spillway is manually factored into the decision process for final site suitability determination. Details of the site score and spillway dimensions are shown in the results summary in Figure 4.

RESULTS AND DISCUSSION

Values of the site score were determined over three pond sizes, three watershed sizes, three cover conditions, two soil (seepage) conditions, and six locations (plus low, medium, and high uniformly distributed rainfall conditions for a total of nine) were included, giving a total of 586 runs. A constant demand of 10 l min^{-1} was used in all runs. Large ponds (five 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. Even with a very small pond, the availability of a uniform rainfall condition would enable sustainability. The primary benefit of the large pond is to enable sufficient storage to last through the dry months. One difficulty of using the large pond and large watershed is the required width of an emergency spillway.

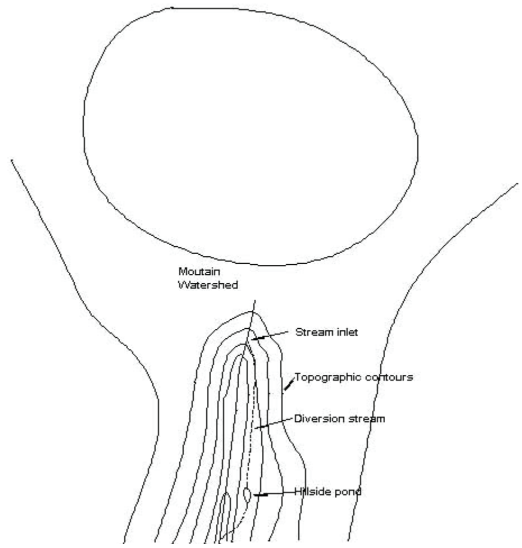


Figure 5. Hillside pond with stream diversion for general purpose water supply. Not shown are levee ponds being supplied at a more or less constant rate from the hillside pond.

Most regions of Honduras have wet and dry extremes during the year. Thus, the assumption of constant base flow and 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 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 diversion strategy is shown in schematic form for a hillside pond in Figure 5. Indeed, a hillside levee can be the basis for an integrated small-scale agricultural production operation that includes fish and other agricultural animal and plant enterprises. Coche et al. (1995) gives additional pictures showing how the diversion approach may be used for levee ponds with direct production. An additional benefit of the diversion would be the reduction in silt accumulation due to the reduced flow.

The use of Excel® as a platform enabled a highly customized model presentation for 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.
Control of the model versions is difficult when users may download the software at their convenience. The model is currently being recoded using Java. We also developed a Java-based interface that enables multiple access of the models that run on a central server, and it also houses the WIDeST website (Verma et al., 2002).

CONCLUSIONS

The steps in using the levee pond balance and the catchment supply evaluation are as follows:

1) Set a management target in consultation with the tilapia specialist;
2) Determine the required water supply to balance seepage and evaporation and meet management-determined volume change targets;
3) Run the catchment analyses on one or more available watersheds to determine a score. Optimize the score by considering diversion strategies;
4) Reevaluate the management target if low site scores are unavoidable (a likely outcome). Consider a production scheme that will reduce water requirements. Repeat the most promising catchment analyses; and
5) Continue the levee balance-catchment analysis iteration until an acceptable water requirement is determined.

The curve number method is generally limited to watersheds smaller than 500 ha. Pond sizes are suggested not to exceed five ha and four m deep due to safety concerns.

ANTICIPATED BENEFITS

Water resources development is increasingly recognized as a critical need in Honduras and many other developing countries. As the popularity of tilapia increases, so will the demand for quality water . This tool is useful for evaluating water resources on upland watersheds (< 500 ha) and can complement larger, basin scale watershed development work. We anticipate continued increases in model usage. The model is currently being used in instruction at Zamorano University and at the University of Georgia. Based on repeat attendees at the series of workshops, we feel that the institutionalization of the model has begun and will continue to grow. We anticipate continued increases in model usage. The model is currently being used in instruction at Zamorano University and at the University of Georgia. In the last class, we were successful in having attendees bring their own laptops with Microsoft Office®, load the software, and use it in a daylong workshop. Working groups have been formed with a nucleus of talent at Zamorano University, and UGA expertise is available via email and chat room software.

ACKNOWLEDGEMENTS

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