# Effects of Watershed-Water Quality-Aquaculture Interactions on Quantity and Quality of Water from Small Catchments in South Africa and Uganda

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## ABSTRACT

The study reveals that water level declines caused by water withdrawal for irrigation could negatively impact aquaculture in multipurpose impoundments. Aquaculture activities in such impoundments might increase plankton production and the planktonic particles could clog irrigation systems. Changes in water quality caused by aquaculture might also negatively impact use of water for domestic purposes. Nevertheless, these effects could be mitigated, and small impoundments seem to be an excellent way of increasing water supply in rural areas. Construction of small impoundments would convert land to aquatic habitat, but overall, the effort probably would increase local ecosystem complexity and be beneficial to biodiversity.

## INTRODUCTION

Acquisition of sufficient water and food for the growing human population is a major issue worldwide and especially in Africa. The traditional way of increasing water supply has been construction of dams on major rivers to impound runoff (Gleick 2004). However, impoundments can be built on small watersheds to impound storm runoff. Such small dams can provide water for agriculture, aquaculture, and community use (Boyd et al. 2010).

In the region around Stellenbosch, South Africa, many small dams have been built to provide water for irrigation, and in recent years, trout have been produced in cages in some of the these reservoirs (Salie 2011; Salie et al. 2008; Maleri et al. 2008). This area could provide a model for construction of multipurpose reservoirs in other regions of Africa.

The purpose of the present study was to make an evaluation of farm dams in the Stellenbosch region with respect to water storage and use, water quality in ponds with and without aquaculture, effects of ponds on local ecosystems with emphasis on biodiversity, and to determine effects of current water use in these impoundments on other possible uses of the water.

## MATERIALS AND METHODS

### Description of ponds and study areas

Three control ponds and three ponds with cage culture were selected. These six ponds are sited on five farms that are located within a 35-km radius of Stellenbosch in the Boland area of the Western Cape Province of South Africa. Stellenbosch region soils developed from a variety of geological materials. The oldest rocks are sedimentary formations of the Malmesbury Group consisting of shales, schists, and greywacke (Theron et al. 1992). The Malmesbury sediments folded into chains of small mountains and were intruded by granite. The landscape eventually subsided and was covered by sands and shales. Erosion of the sands and shales exposed the remnants of the Table Mountain Group and low granite hills and in front of these formations the coastal plain of the Western Cape developed (Theron et al. 1992).

Farms for this study are on the slopes between the mountains and granite hills (Stellenbosch, Helderberg, Simonsberg, and Drakenstein Ranges) and the coastal plain. Soils on these slopes tend to be highly weathered, sandy, and acidic (pH 5-5.5), and they contain considerable quantities of stone (Conradie et al. 2002). Soils are of the Tukulu, Vilafontes, Avalon, Oakleaf, Glenrosa, Hutton, and Westleigh types.

Climate in the Western Cape region is classified as mild Mediterranean with mean monthly temperatures between 13°C in September and 22°C in February (Conradie et al. 2002), and rainfall measures up to about 1,000 mm/yr (Walkingholidays.co.za). The natural vegetation is known as fynbos that consists of fine-leafed, thick, shrub-like plants, but much of this vegetation has been replaced with alien species – eucalyptus, acacias, pine, oaks, poplars, fruit trees, pasture grasses, vineyards, and exotic weeds. Because of high water use by alien plants compared to native, fynbos vegetation (Dye and Versfeld 2007), the South African government has initiated programs to remove alien species from areas not devoted to agriculture and forestry and re-establish fynbos vegetation on these tracts.

Specific information on ponds and watersheds is provided in Table 1. The ponds under the heading cages were sites for cage culture of rainbow trout. The estimated production of trout in 2010 was 6,000 kg in Mountain Vineyards, 12,000 kg in Patryskloof, and 18,000 kg in Blue Gum. Trout fingerlings were stocked in April and fed three times daily with a 38% crude protein content, pelleted feed at about 3% of estimated body weight per day. Marketable-sized trout were harvested between October and December.

### Water analyses

Water samples were collected by dipping water from pond surfaces at monthly intervals from January to August 2011. These samples were analyzed for pH, temperature, dissolved oxygen, electrical conductivity, total alkalinity, total hardness, total phosphorus, total ammonia nitrogen, nitrate-nitrogen, nitrite nitrogen, iron, manganese, zinc, and copper (Eaton et al. 2005). The Secchi disk visibility also was measured on each sampling date.

### Hydrologic measurements

Historical data on air temperature, rainfall, and Class A pan evaporation in the area were available from Conradie et al. (2002), but data specifically for the study ponds were unavailable. Watershed runoff was estimated by the water accounting method described by Yoo and Boyd (1994). The Thornthwaite method (Thornthwaite and Mather 1957) allowed calculation of monthly evapotranspiration rates needed in the water accounting method for estimating runoff.

Pond water levels were measured at weekly intervals from 19 January to 1 September 2011 with aid of a modified staff gauge. Project funds were inadequate to allow installation of water flow measuring devices for inflow of streams to ponds, overflow from ponds, and water removed from ponds for use in irrigation. Pond capacities and areas at full-pool level were obtained from design drawings for original pond construction.

### Watershed observations

The areas of watersheds were delineated from satellite imagery, and the shoreline distances of ponds were also obtained from these images. Watershed cover was assessed visually. Farmers provided information about land use management practices on watersheds.

## RESULTS

### Watersheds and ecology

Only two of the farms, Vergelegen and Boschendal, had significant area of native fynbos vegetation; the other watersheds were devoted almost entirely to forestry and agriculture (Table 1). All farms had agricultural activities on pond watersheds, and fertilizers and pesticides were routinely applied to crops. The common pesticides used and active ingredients in them are presented in Table 2:

Ponds were located in former agricultural land, and pond construction resulted in disruption of the areas around the ponds. The denuded areas typically were invaded by alien species, especially weeds. The pond water levels decline greatly during the dry season exposing large areas of denuded soil, but because of lack of moisture, these areas do not re-vegetate before ponds are refilled by runoff during rainy months.

Ponds in humid climates typically have wetland areas around edges and in upper ends where water inflow tends to be greatest (Chaney et al. 2012). Because of the rapid and great change in water level during the dry season when water is removed for irrigation, wetland areas have not developed around the edges of ponds selected for this study. Wetland vegetation has developed in small water courses that conveyed water into ponds and received pond overflow during the wet season. These areas ranged in size from 1,000 $m^2$ to about 5,000 $m^2$ in the inflow and outflow zones of each pond.

Water sources for the ponds are: direct rainfall, sheet flow runoff from watersheds, groundwater seepage during the wettest periods (De Groeve 2003), and inflow of ephermal streams. Inflowing streams had diversion structures that conveyed a portion of their flow away from ponds and into the natural watercourse to maintain downstream flow.

A number of species of wetland plants were observed in the inflow and outflow areas to include *Typha capensis*, *Scirpus* sp., *Zantedeschia arthiopica*, *Pteridium* spp., *Phragmites* australis, *Ischryro lepis*, *Restio* sp.; *Cliffortia* spp., *Pennisetum macrourum*, *Senecio halimnifolius*, *Juncus karusii*, and *Passerina paludosa*. These plants created habitat for amphibians, reptiles and small birds.

The open water areas of the ponds created habitat for birds. Herons, kingfishers, Egyptian geese, fish eagles and cormorants were observed in and around the ponds. Frogs were seen in the ponds, and deer, baboons, and several species of small mammals were observed drinking water from the ponds.

The ponds also contain fish that have been stocked purposely (in addition to those used in aquaculture cages) or entered naturally. The fish include bass, carp, tilapia, and catfish, and trout.

These observations suggest that the ponds have increased the amount of aquatic habitat and enhanced biodiversity in the study area. In addition, they provide irrigation water critically needed for crops and allow the possibility for commercial aquaculture. The ponds also could supply water for livestock and domestic use if necessary.

### Water balance

None of the ponds had water pumped into them from other ponds or streams during the study. However, it is not uncommon at some ponds in the area for farmers to pump water from streams into ponds to supplement water entering from watersheds.

There was no feasible way to estimate the quantity of water diverted from ponds to support downstream flow. Thus, it was impossible to obtain sufficient data for making detailed water budgets for the ponds as originally planned. We had to focus on estimating the water balance for hypothetical, 1-ha watershed units and 1-ha pond units for conditions existing in the Stellenbosch region.

Net seepage from ponds in the area was estimated to be 190 mm/month (De Groeve 2003). These data allowed an estimation of the water balance (excluding runoff into ponds) for a 1-ha area of pond surface. Inflow by rainfall would average 6,910 $m^3$/ha/yr, but outflow through seepage and evaporation would be 35,230 $m^3$/ha. Thus, the water balance is -28,320 $m^3$/ha. The water for replacing seepage and evaporation losses and maintaining pond volume must be provided by runoff from pond watersheds.

The average moisture holding capacity of soils in the study area was reported to be about 125 mm/m of soil depth and the plant root zone extends to roughly 1 m in the soil (Conradie et al. 2002). This information allowed runoff to be estimated by the moisture accounting method (Table 3). Runoff will occur in June, July, August, and September, and the average annual runoff should be about 153 mm (about 22% of annual rainfall) or 1,530 $m^3$/ha/yr. Thus, 18.5 ha of watershed would be necessary to provide enough runoff to compensate for the excess of seepage plus evaporation over direct rainfall into ponds. An additional 6.5 ha of watershed would be needed for each 1 m depth of storage volume over 1 ha of pond surface area. Thus, a 10-m deep pond would require a watershed area of 83.5 ha/ha of water surface area.
Calculations above assume that the entire watersheds of ponds were located on the slopes of the granite mountains at the upper ends of the watersheds. However, a portion of all watersheds was located on the mountains, but the area of the watersheds that consisted of granite outcrops could not be estimated from the maps and satellite images available.

The moisture holding capacity of these granite outcrop areas is essentially nil. The runoff estimations should be adjusted for these areas, because almost all of the rain falling on rock outcrops would be converted to runoff. To illustrate the problem with runoff estimates, Patryskloof Dam at Cape Olive Farm is 4 m average depth and has a watershed area of 530 ha. Based on the runoff estimate (Table 3), this pond would need 132.5 ha of watershed area, and it has 530 ha. This pond has plenty of watershed area to fill in a normal year. However, Ashanti Dam at Ashanti Farm would need 1,707 ha of watershed to fill on a normal year, and the watershed area provided by the farm manager is only 320 ha. Nevertheless, this pond fills with water. Obviously, we need to obtain more accurate data on watershed areas and watershed soils in order to assess runoff more accurately.

### Water levels

Water levels decreased steadily during the period January through May. However, water levels began to increase in June in response to greater rainfall, lower evaporation rates, and cessation of water removal for irrigation during the winter. By September, water levels were near the levels observed in January.

### Water quality

Water quality data are summarized in Table 4. Although there were no large differences among ponds within the control group and the aquaculture group or between the two groups, there was a tendency of greater ammonia and nitrate concentrations in the ponds with aquaculture. This is not surprising considering that feeds were applied to the cages. Earlier studies are in agreement and suggested that feed inputs also lead to greater phytoplankton productivity (Maleri et al. 2008).

The water quality in the ponds also was suitable for livestock watering and many other domestic uses. For use in households, the water probably would need to be clarified by alum treatment and boiled or treated with chlorine to assure a sanitary condition.

## DISCUSSION

Although it was impossible to make a detailed water budget for each pond because of the lack of accurate information on water withdrawal and diversion from ponds for irrigation and downstream flow, the study revealed that these multipurpose ponds had drastic declines in water level as a result of water use for irrigation. Although trout culture was possible because water levels remained fairly high during the cooler part of the year, such ponds, if located in warmer climates might not be suitable for aquaculture because of poor water quality and crowding of fish when water levels are low. Of course, cage culture would be possible during periods when water levels are high.

The ponds resulted in conversion of land to water surface, but in the semi-arid climate of South Africa, the formation of permanent water surfaces and small areas of wetland associated with the ponds is no doubt beneficial by creating an ecosystem complexity and increasing biodiversity.

The main purpose of ponds in this study was for irrigation, and nutrients from aquaculture would possibly enhance the benefits obtained from the water for this purpose. However, it has been suggested in earlier studies that increased phytoplankton production in ponds as a result of aquaculture could result in clogging or irrigation systems (Koegelenberg et al. 2002; du Plessis 2007). Aside from possibly clogging irrigation systems, eutrophication of ponds likely would not be of other concern in the Stellenbosch area. In other areas where pond water would be used for domestic purposes in addition to irrigation, eutrophication would possibly be of other concerns such as excessive turbidity, undesirable color, and taste and odor problems.

## ANTICIPATED BENEFITS

This study suggests that multipurpose ponds could be a valuable water supply for many rural areas and especially in African countries. Construction of such ponds would cause changes in land use – terrestrial habitat to water surfaces and wetlands. Nevertheless, the inclusion of such areas in the landscape would have a beneficial effect on local ecosystems. However, such projects would be hydrologically complex, and much more research is needed for development of guidelines for pond site selection, design, construction, and operation.

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Table 1. Description of ponds used in study of water quality, hydrology, and watersheds in Stellenbosch region of South Africa. The controls had no aquaculture, but trout were produced in cages in the ponds listed under aquaculture.

| Name of Pond | Farm | GPS coordinates | Area (ha) | Volume ($m^3$) | Average depth (m) | Shoreline (m) | Watershed cover |
|---|---|---|---|---|---|---|---|
| Controls | | | | | | | |
| Rooiland | Vergelegen | 34° 4' 52.14" S<br>18° 54' 38.72" E | 23.7 | 2,700,000 | 11.4 | 2,240 | Fynbos and vineyard |
| Normandie | Boschendal | 33° 53' 12.97" S<br>18° 59' 5.77" E | 11.8 | 720,000 | 6.1 | 1,500 | Fynbos and vineyard |
| Ashanti | Ashanti | 33° 43' 35.425" S<br>19° 1' 52.21" E | 14.3 | 1,170,000 | 8.2 | 2,000 | |
| Aquaculture | | | | | | | |
| Blue Gum | Lourensfard | 34° 1' 55.07" S<br>18° 55' 54.49" E | 16.8 | 1,700,000 | 10.1 | 1,980 | Olive, fruit, eucalyptus, pine trees, and vineyard |
| Mountain Vineyards | Boschendal | 33° 52' 24.88" S<br>18° 57' 20.43" E | 8.0 | 675,000 | 8.4 | 1,370 | Fruit trees, vineyards, and pasture |
| Patryskloof | Cape Olive | 33° 42' 26.19" S<br>19° 2' 1.23" E | 7.0 | 280,000 | 4.0 | 1,160 | Olive trees |

Table 2. List of pesticides used on farms that could possibly have entered waters.

| Type | Product | Active ingredient |
|---|---|---|
| Fungicide | Kumulus | Sulphur |
| | Vivando | Metrafenone |
| | Cabrio | Strobulin |
| | Talendo | Penconazole |
| | Svitch | Fudioxinil ciprodinyl |
| | Topaz | Pencanozole |
| | Mancozeb | Dithiocarbamate |
| | Captab | Calcium polycarbophil |
| Insecticide | Proandub | Glyfosate |
| Herbicide | Gramoxone (preglove) | Paraquat dichloride |
| | Fuzilade | Flazifop-p-butyl |
| | Aromasin | Exemestane |

Table 3. Estimation of runoff by the soil moisture accounting method.

| | Month | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable (cm) | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb |
| Soil moisture at beginning month | 0 | 0 | 0 | 41 | 125 | 125 | 125 | 125 | 105 | 77 | 8 | 0 |
| Rain during month | 16 | 48 | 88 | 140 | 95 | 96 | 60 | 42 | 45 | 31 | 18 | 12 |
| Total available moisture for month | 16 | 48 | 88 | 181 | 220 | 221 | 185 | 167 | 150 | 108 | 36 | 12 |
| Potential evapotranspiration during month | 82 | 63 | 47 | 36 | 34 | 44 | 40 | 62 | 73 | 100 | 102 | 102 |
| Soil moisture remaining at end of month | 0 | 0 | 41 | 145 | 186 | 177 | 145 | 105 | 77 | 8 | 0 | 0 |
| Soil moisture holding capacity of soil | 125 | 125 | 125 | 125 | 125 | 125 | 125 | 125 | 125 | 125 | 125 | 125 |
| Runoff during month | 0 | 0 | 0 | 20 | 61 | 52 | 20 | 0 | 0 | 0 | 0 | 0 |

Table 4. Water quality data for ponds with cage culture and without cage culture.

| | Cages | | | Controls | | |
|---|---|---|---|---|---|---|
| Variable | Mountain Vineyards | Cape Olive | Blue Gum | Normandi | Ashanti | Rooiland |
| Temperature ($^oC$) | 19.8 ± 3.4 | 18.6 ± 2.6 | 20.9 ± 4.5 | 20.4 ± 2.6 | 20.3 ± 2.7 | 20.8 ± 2.5 |
| Dissolved oxygen (mg/L) | 8.25 ± 0.67 | 8.54 ± 0.91 | 9.26 ± 1.11 | 7.93 ± 0.52 | 8.68 ± 0.64 | |
| pH | 7.09 ± 0.36 | 7.22 ± 0.32 | 7.40 ± 0.06 | 7.00 ± 0.20 | 7.57 ± 0.37 | 7.27 ± 0.20 |
| Secchi disk (cm) | 124 ± 59 | 58 ± 36 | 147 ± 90 | 144 ± 168 | 96 ± 49 | 57 ± 27 |
| Conductivity (mS/m) | 7.28 ± 0.79 | 8.81 ± 1.20 | 5.70 ± 1.18 | 4.33 ± 0.72 | 13.16 ± 0.94 | 15.14 ± 1.78 |
| Total alkalinity (mg/L) | 12.5 ± 2.7 | 8.4 ± 0.8 | 6.1 ± 1.6 | 4.1 ± 0.7 | 18.8 ± 1.6 | 14.1 ± 0.8 |
| Total hardness (mg/L) | 16.1 ± 2.4 | 17.7 ± 6.2 | 15.9 ± 3.2 | 12.5 ± 2.9 | 25.4 ± 4.6 | 17.7 ± 3.5 |
| Phosphorus (mg/L) | 0.018 ± 0.025 | 0.018 ± 0.021 | 0.028 ± 0.038 | 0.014 ± 0.018 | 0.042 ± 0.045 | 0.015 ± 0.020 |
| Total ammonia N (mg/L) | 0.33 ± 0.16 | 0.31 ± 0.13 | 0.56 ± 0.38 | 0.19 ± 0.08 | 0.40 ± 0.16 | 0.27 ± 0.12 |
| Nitrate N (mg/L) | 0.75 ± 0.76 | 0.15 ± 0.20 | 0.18 ± 0.19 | 0.13 ± 0.11 | 0.40 ± 0.43 | 0.22 ± 0.15 |
| Nitrite N (mg/L) | 0.014 ± 0.006 | 0.021 ± 0.007 | --- | 0.023 ± 0.017 | 0.030 ± 0.020 | --- |
| Iron (mg/L) | 0.079 ± 0.042 | 0.387 ± 0.105 | 0.463 ± 0.451 | 0.296 ± 0.384 | 0.537 ± 0.594 | 0.540 ± 0.220 |
| Manganese (mg/L) | 0.001 ± 0.002 | 0.002 ± 0.002 | 0.016 ± 0.019 | 0.020 ± 0.020 | 0.082 ± 0.120 | 0.010 ± 0.011 |
| Copper (mg/L | 0.003 ± 0.003 | 0.002 ± 0.002 | 0.001 ± 0.001 | 0.006 ± 0.007 | 0.002 ± 0.003 | 0.003 ± 0.005 |
| Zinc (mg/L) | 0.005 ± 0.004 | 0.006 ± 0.003 | 0.009 ± 0.003 | 0.010 ± 0.003 | 0.012 ± 0.006 | 0.004 ± 0.003 |