



# Nogales Flood Detention Study

By Laura M. Norman, Lainie Levick, D. Phillip Guertin, James Callegary, Jesús Quintanar Guadarrama, Claudia Zulema Gil Anaya, Andrea Prichard, Floyd Gray, Edgar Castellanos, Edgar Tepezano, Hans Huth, Prescott Vandervoet, Saul Rodriguez, Jose Nunez, Donald Atwood, Gilberto Patricio Olivero Granillo, and Francisco Octavio Gastelum Ceballos

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## Acronyms

ADEQ-OBEP:	Arizona Department of Environmental Protection- Office of Border Environmental Protection
ADWR:	Arizona Department of Water Resources
AGWA:	Automated Geospatial Watershed Assessment
CILA:	La Sección mexicana de la Comisión Internacional de Límites y Aguas
CONAGUA:	Comisión Nacional del Agua
DEM	Digital Elevation Model
GIS:	Geographic Information System
GPS:	Global Positioning System
IBWC:	International Boundary and Water Commission
IMIP:	Instituto Municipal de Investigación y Planeación
K2:	KINEROS2: Kinematic Runoff and Erosion Model
LiDAR:	Light Detection And Ranging
NED:	National Elevation Dataset
NOAA:	National Oceanic and Atmospheric Administration
NORCOMM	U.S. Department of Defense's Northern Command
OOMAPAS-NS:	Water and Wastewater Utility, Nogales, Sonora
TAAP:	Transboundary Aquifer Assessment Project, Tucson, Arizona
UA-SNRE:	University of Arizona-School of Natural Resources and Environment
USACE:	U.S. Army Corps of Engineers
USDA-ARS-SWRC:	U.S. Department of Agriculture-Agricultural Research Station-Southwest Watershed Research Center
USGS:	U.S. Geological Survey

## Conversions

1 cubic meter (m<sup>3</sup>) = 35.314 666 721 cubic foot (ft<sup>3</sup>)

1 meter (m) = 3.280 839 895 feet (ft)

# Nogales Flood Detention Study

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## Abstract

Flooding in Ambos Nogales often exceeds the capacity of the channel and adjacent land areas, endangering many people. The Nogales Wash is being studied to prevent future flood disasters and detention features are being installed in tributaries of the wash. This paper describes the application of the KINEROS2 model and efforts to understand the capacity of these detention features under various flood and urbanization scenarios. Results depict a reduction in peak flow for the 10-year, 1-hour event based on current land use in tributaries with detention features. However, model results also demonstrate that larger storm events and increasing urbanization will put a strain on the features and limit their effectiveness.

## 1.0 Introduction

The cities of Nogales, Sonora, and Nogales, Arizona, are located across from each other along the Mexico-United States border in the Ambos Nogales Watershed, a topographically irregular bowl-shaped area with a northward gradient. Throughout recent history, residents in both cities have been affected by flooding. The primary means of regulating this runoff is a series of detention features in Nogales, Sonora. A detention feature is a stormwater management facility. Many of these features have proven inadequate in the face of rapidly increased urban growth, and land managers on both sides of the border seek information to increase the effectiveness of detention features by optimizing future locations. In addition, managers seek to understand and characterize the impact of various land cover types on local runoff to mitigate flood hazards through informed land-use planning strategies.

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One way to capture and visualize the impacts of detention features and land use in a watershed is through hydrologic modeling. The KINEROS2 (K2), with the Automated Geospatial Watershed Assessment (AGWA) 2.0 geographic information system (GIS) interface, is one such model that can be used to identify flood-prone areas, simulate the impact of land-use change, and evaluate the impact of potential flood-control interventions (Woolhiser and others, 1990). Using relatively coarse-scale input data, Norman and others (2010a) employed the K2 model to evaluate the Ambos Nogales watershed's vulnerability to flooding.

The demonstration of this model's utility to simulate potential flooding impacts prompted the International Boundary and Water Commission (IBWC) to implement a higher resolution study on the impacts of the detention features that have been constructed in Nogales, Sonora. The refined modeling provides a more accurate understanding of the volume of water being detained by these features under various scenarios and the magnitude of discharge for the return periods studied—10, 25, and 100 years. The modeling also provides a way to capture the impact of rapid land-use changes in Nogales, Sonora. The city is growing rapidly without much regard to slope, location of washes, or infrastructure capacity. Within Nogales, Sonora, the 2000 census recorded a population of 159,787, with an annual growth rate of 4.9 percent. In 2009, unofficial estimates suggest the population is closer to 300,000. On the basis of urban growth scenarios predicted by Norman and others (2009), the SLEUTH model predicted that the Nogales, Sonora, urban area would grow to almost 3.5 times its 2002 size by 2030.

This study reports the results of K2 modeling in Ambos Nogales using higher resolution data on land cover, land use, and detention-feature geometry. The resulting information can be used in planning flood management for the twin-cities area of Ambos Nogales.

## **1.1 KINEROS2**

Although several models exist for watershed modeling, the KINematic Runoff and EROSION model (KINEROS2; K2) has advantages because it can be adapted to visualize impacts of urban development or detention features on a watershed. K2 is a physically based hydrologic model that represents watersheds by a cascade of overland-flow planes and channels. Representing spatial variation of rainfall, infiltration, runoff, and erosion parameters can all be accommodated. We chose K2 for this study because it can simulate increasing impervious surfaces or land-use changes that influence the volume of water that runs off and the amount of sediment that can be moved in a watershed while precipitation remained constant and spatially uniform (Woolhiser and others, 1990; Smith and others, 1995). K2 has also been extensively tested in southern Arizona and should be suitable for the Nogales watershed. Data required to run K2 are as follows:

1. Watershed delineation: Watershed boundaries and topography control the direction of water flow across the landscape.
2. Rainfall: The amount, distribution, intensity, and duration of rainfall determines the total amount of water redistributed and processed by the watershed for a given event.
3. Land use: The type of land cover affects the flow of water locally because of friction and infiltration. Impermeable surfaces, such as rooftops and pavement, increase runoff amounts in urban areas.
4. Detention features: The location and geometry of detention features modify flow within the stream channel.

Given these inputs that describe initial conditions, the K2 model will output a hydrograph that predicts flow at any specified stream location. Development of the various input layers for this study is described below.

## **2.0 Watershed Delineation**

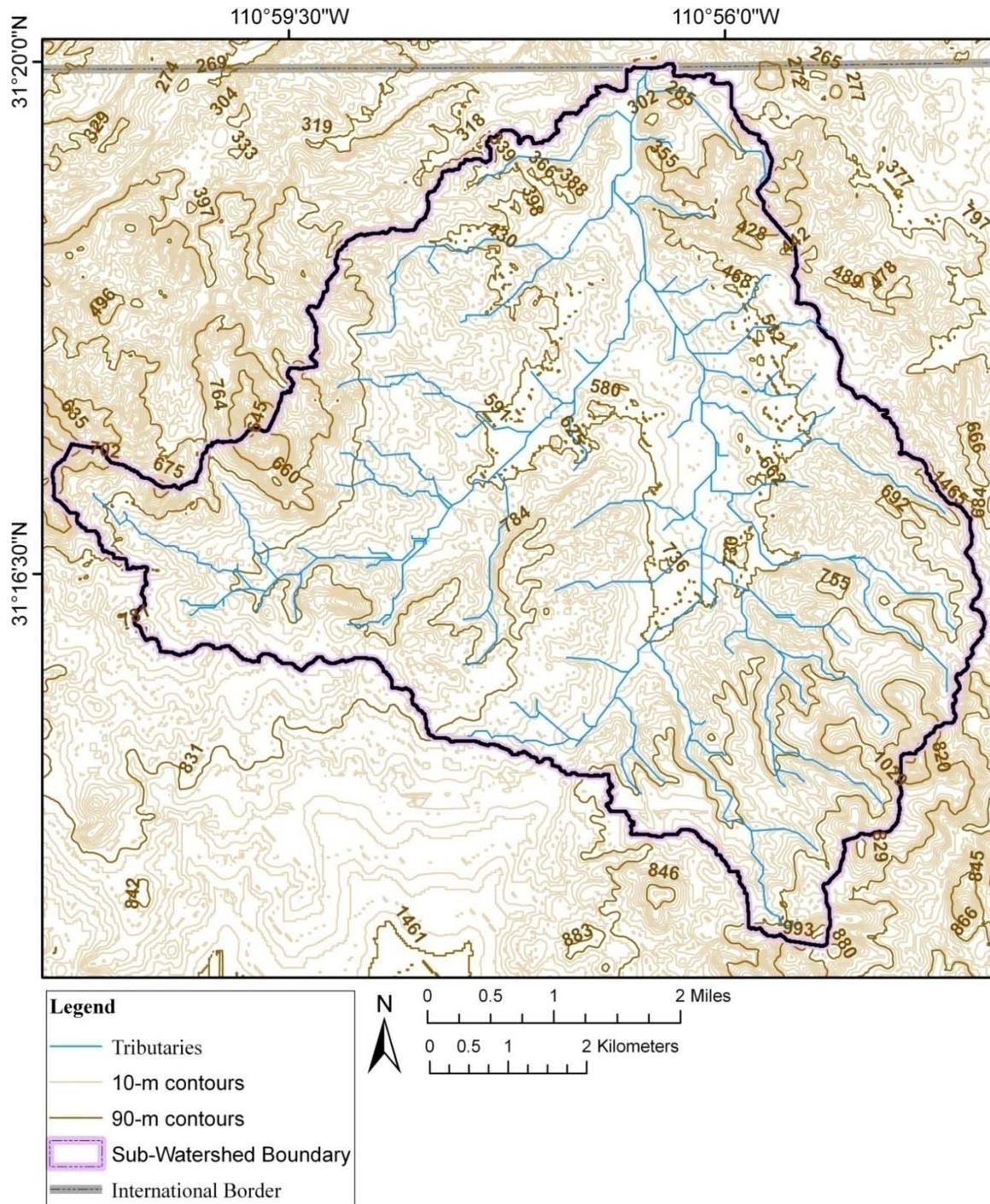
We chose to model the sub-watershed of the Ambos Nogales that has the pedestrian border crossing point as its outlet, because this feature has significantly modified the hydrology and most of the detention features are located upstream from this crossing. We accessed the National Elevation Dataset (NED) elevation data product produced and distributed by the United States Geological Survey (USGS) through The National Map Seamless Server (<http://ned.usgs.gov/>) at a resolution of 1/3 arc-second (approx. 10 m.) for the Nogales study area. The NED data are considered to be the "best available" data from the USGS. Contours were created for 10-meter and 90-meter intervals. Based on hydrological modeling processes within the GIS, streams were mapped for the study area as described below. The Nogales Wash originates 6.72 miles (10.83 km) south of the border. Using these data and the known border crossing point for pedestrians, an outlet was selected and a sub-watershed delineated using the AGWA 2.0 platform. The main branch of the Nogales Wash has a contributing area in Nogales, Sonora, of 25.79 square miles (66.8 km<sup>2</sup>) that discharges into Nogales, Arizona (fig. 1). Actions to control and regulate dangerous flows into the urban areas of Ambos Nogales are being carried out primarily upstream in Mexico within this sub-watershed.

## **3.0 Rainfall**

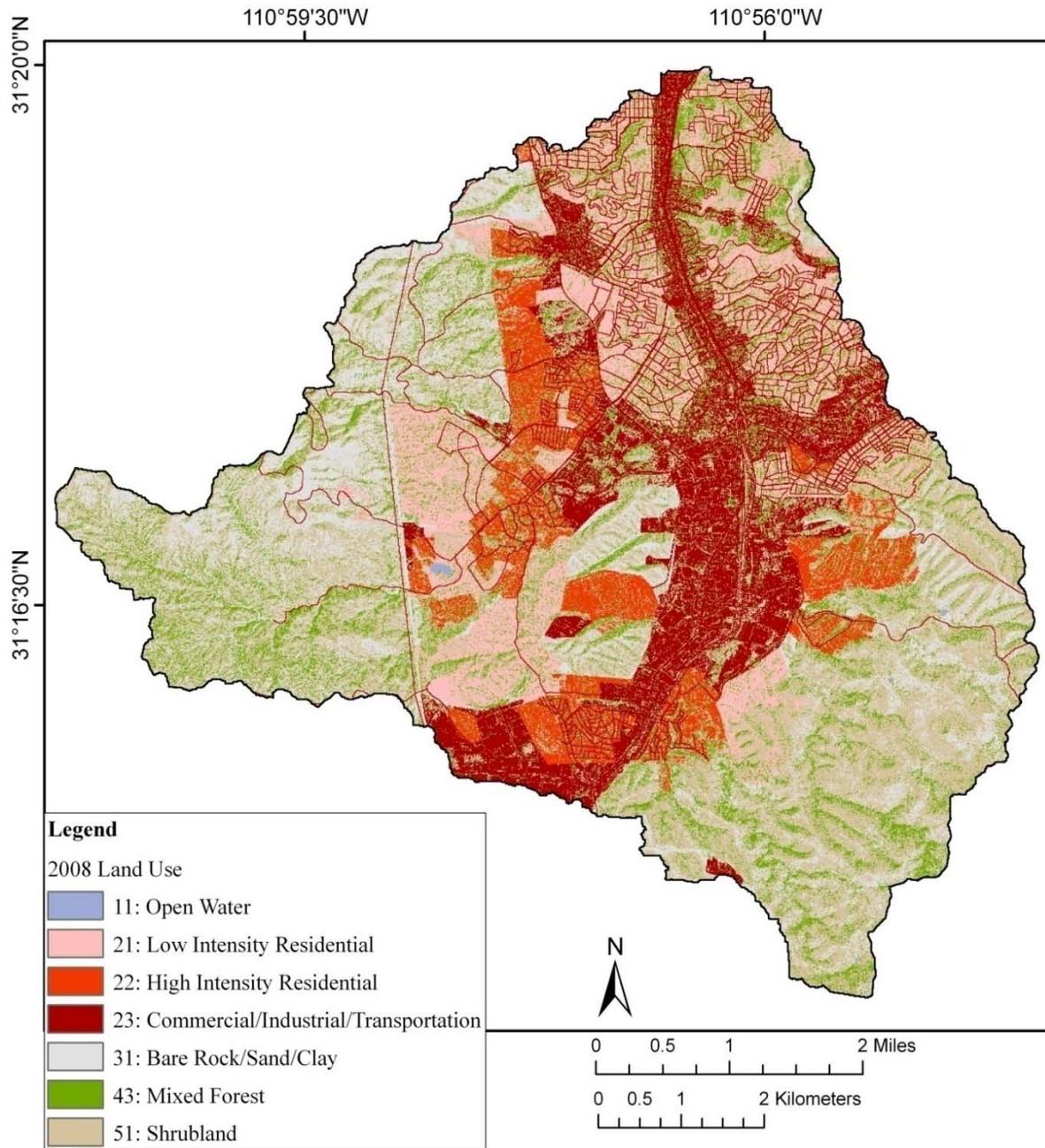
Rainfall was modeled as spatially uniform across the watershed, so that it is not a complicating factor when the objective is assessment of land-use/cover change. Variations of homogeneous-design storms were dictated by the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 for Arizona (Bonnin and others, 2006). Precipitation depth (inches) was extracted at site—Nogales, Arizona (Site no. 02-5921): latitude 31.35°N and longitude 110.9167°W (3,907 ft) from Bonnin and others (2006) and used in the model. A variety of rainfall events for K2, including a 10-year 1-hour (1.82 in.), a 25-year 6-hour (2.93 in.), and a 100-year 6-hour (3.76 in.) flood event were used to investigate the relative impacts of land cover change on short versus long return period storms.

## **4.0 Land Use Map**

A heterogeneous land cover dataset developed by Norman and Wallace (2008) for the original K2 modeling of the Ambos Nogales watershed, derived from 60-m resolution Landsat imagery acquired on October 7, 1992, was too coarse to support input needed for calculating the hydrological parameters of a small watershed and associated detention features. A higher resolution land-use map was developed for this project using 1-m. resolution aerial photos of Nogales, Sonora, acquired in 2008 (fig. 2). A paper describing the production of this 10-m. land-use map and descriptions of the procedure employed to test its accuracy using recent orthophotos of the Nogales, Sonora, watershed was published in July 2010 (Norman and others, 2010b).



**Figure 1.** Map of international border between the United States and Mexico with derived topographic lines, tributaries, and sub-watershed boundary for the Nogales, Sonora, sub-watershed based on 10-m. National Elevation Dataset.



**Figure 2.** A 10-meter resolution land-use map, derived from 2008 aerial photos of the Nogales, Sonora, sub-watershed.

## 5.0 Detention Features

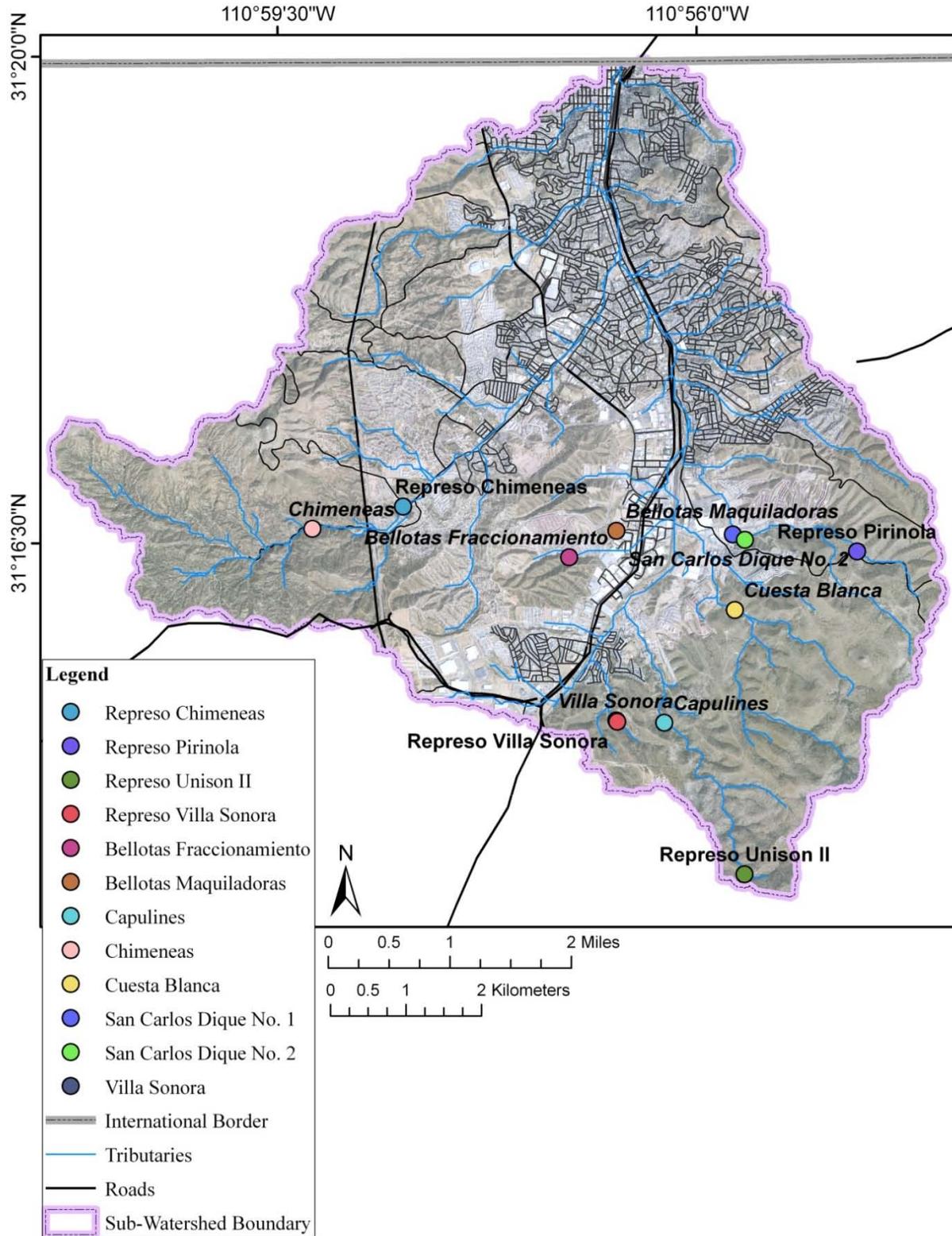
A detention feature consists of an embankment dam and associated upstream basin installed in a stream to protect against flooding and downstream erosion. Detention basins are designed to store runoff volume and discharge it slowly to reduce the peak discharge downstream, reducing associated flash-flood hazards. An embankment dam is an artificial water barrier typically created by the compaction of various compositions of soil, sand, clay, and/or rock with a semipermanent waterproof natural covering. Water is transmitted through these features via culverts or tunnels built within the base of the dam.

Embankment dams typically come in two types: the earthen dam and the rock-filled dam. Within the Nogales, Sonora, sub-watershed, some new dams are being constructed and some are being rehabilitated by Mexico's National Water Commission (CONAGUA). In addition, a rock-filled (gabion-type) flood detention feature, made like caged rip-rap, is being used in the City of Nogales. This differs from the other detention features as it is porous and constructed across the banks of the streambed and works to attenuate flash floods. Locations for the installation of gabion-type flood detention features to reduce flood-stage discharges in washes are based on the recommendations of the U.S. Army Corps of Engineers using the HEC-RAS model (U.S. Army Corps of Engineers, 2005).

In this study, we modeled the impacts of the various types of detention features in terms of changes in peak flow and discharge in cubic meters per second. Locations and descriptions were provided by Gilberto Patricio Olivero Granillo, Claudia Zulema Gil Anaya, Monica Audelo, and Julio Luna Rodríguez (table 1; see also fig. 3 and appendix A). For modeling purposes, the San Carlos Dique 1 and Dique 2 earthen dams were simulated as one feature because they are located close together. The Villa Sonora 1 and 2 earthen dams were also combined because they are located close together. With these dams combined for the modeling, there were a total of 10 locations simulated.

**Table 1.** Embankment dams identified for modeling in this study.

<p>Rock Gabion Dams being constructed by the City:</p> <ul style="list-style-type: none"> <li>• Capulines</li> <li>• Cuesta Blanca</li> <li>• Bellotas Fraccionamiento</li> <li>• Bellotas Maquiladoras</li> <li>• Chimeneas</li> </ul>	<p>Earthen dams being rehabilitated by CONAGUA:</p> <ul style="list-style-type: none"> <li>• Represa Chimeneas</li> <li>• Represa Villa Sonora 1 &amp; 2</li> <li>• Represa Pirinola</li> <li>• Represa Unison II</li> </ul> <p>Earthen dams being constructed by the City:</p> <ul style="list-style-type: none"> <li>• San Carlos Dique 1 &amp; 2</li> </ul>
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**Figure 3.** Location map depicting detention features (circles shown in various colors), in relationship to tributaries and roads in the Nogales, Sonora, sub-watershed.

## 5.1 Meetings and Field Trips

A series of meetings and field trips began the process for collecting necessary data for the modeling of the detention features. A kick-off meeting was held on January 19, 2010, in Nogales, Arizona, at which a presentation was delivered with simultaneous translation (Spanish and English) describing the modeling effort being funded by the IBWC and the measurements that were collected at each site (fig. 4). An agenda was distributed prior to and a worksheet was distributed at the meeting for colleagues to fill out and mail back (appendix A).



**Figure 4.** Photograph of binational collaborators (from left to right), back row: Gilberto Patricio Olivero Granillo, Agustin Varela Orozco, Francisco Octavio Gastelum Ceballos, Alejandro Barcenas, Donald Atwood, Jesús Quintanar Guadarrama, Hans Huth; front row: Lainie Levick, Claudia Zulema Gil Anaya, and Laura Norman.

Field trips were planned for researchers from the USGS to travel to Nogales, Sonora, to acquire measurements and photographs but were postponed several times because of travel restrictions and violence in the study area. Three trips were finally taken (summarized below); the detention-feature diagrams, measurements taken, and photographs are available in appendix A.

On March 24, 2010, Andrea Harrop Prichard and Prescott Vandervoet from the University of Arizona, Udall Center for Studies in Public Policy, and researchers for the Transboundary Aquifer Assessment Program (TAAP) surveyed the Chimineas and Represa Chimineas features with engineers and technicians from IMIP (Claudia Gil, Edgar Castellanos, and Edgar Tepezano) and OOMAPAS.

On April 13, 2010, James Callegary and Floyd Gray (USGS), and Hans Huth (Arizona Department of Environmental Quality) visited Nogales. Jesus Quintanar facilitated the visit. Ing. Claudia Gil helped with the visit with Edgar Castellanos and Edgar Tepezano. Of the basins used in this model only the Represa Pirinola was surveyed during this trip.

On May 19, 2010, Floyd Gray and Andrea Prichard made a final reconnaissance field trip to the detention features in Nogales, Sonora, with Ing. Gil, Quintanar, Rodriguez, Tepezano, and Castellanos (fig. 5). The detention features of Maquiladoras (also called Maquillas), Bellotas, Capulines, Represa Villa Sonora, Represa Unison II, and Cuesta Blanca were all surveyed during this trip.



**Figure 5.** Photo of field trip group picture (from left to right): Jesus Quintanar, Claudia Gil, Floyd Gray, Saul Rodriguez, Andrea Prichard, Edgar Castellanos, Edgar Tepezano. (Photograph by A. Prichard.)

## 5.2 Modeling

Following on Milczarek and others (2004) and Norman and others (2010a), we used the AGWA 2.0 tool to parameterize the K2 model to simulate the impacts of the detention features and land use. The internal gages function was used in the AGWA tool to represent the location of the detention features. This effectively subdivides the watershed at each detention feature location, permitting evaluation of flow at that location.

The AGWA Land Cover Modification Tool generates a multifractal surface with multiple land cover types. The result is a surface consisting of spatially randomly distributed patches within any polygon area defined by the user. This was used to convert the watersheds above each detention feature to “developed” land for the future land-cover simulations. Two modified land covers were created for each watershed: “Urb1,” with open space preserved (33 percent developed open space, 33 percent developed low intensity, and 34 percent developed medium intensity) and “Urb2,” with no open space preserved (33 percent developed low intensity, 34 percent developed medium intensity, and 33 percent developed high intensity).

These three land use scenarios were modeled with and without the detention feature for all three design storms at each of the 10 embankment dam locations, totaling 174 simulations. Each location was simulated for all conditions, except Maquilas, which is already developed and was simulated only for current land use and the “Urb2” land use. The Pirinola rock gabion dam is located within the watershed (upstream) of the Nogales/San Carlos Dique 1 & 2 earthen dams; therefore it is included in the results for Dique 1 & 2. The Chimeneas rock gabion dam is located within the watershed (upstream) of the Chimeneas earthen dam and is likewise included in the results for the earthen dam.

- 1) **Current Land Use** (Norman and others, 2010b)
  - i) **Without any detention feature**
    - (a) 10 year 1 hour
    - (b) 25 year 6 hour, and
    - (c) 100 year 6 hour storms.
  - ii) **With the dam**
    - (a) 10 year 1 hour
    - (b) 25 year 6 hour, and
    - (c) 100 year 6 hour storms.
- 2) **“Urb1”**: 33 percent developed open space, 33 percent developed low intensity, and 34 percent developed medium intensity
  - i) **Without any detention feature**
    - (a) 10 year 1 hour
    - (b) 25 year 6 hour, and
    - (c) 100 year 6 hour storms.
  - ii) **With the dam**
    - (a) 10 year 1 hour
    - (b) 25 year 6 hour, and
    - (c) 100 year 6 hour storms.
- 3) **“Urb2”**: 33 percent developed low intensity, 34 percent developed medium intensity, and 33 percent developed high intensity
  - i) **Without any detention feature**
    - (a) 10 year 1 hour
    - (b) 25 year 6 hour, and
    - (c) 100 year 6 hour storms.
  - ii) **With the dam**
    - (a) 10 year 1 hour
    - (b) 25 year 6 hour, and
    - (c) 100 year 6 hour storms.

### 5.3 Assumptions

- The location of each dam is as close as possible to the actual location based on our Digital Elevation Model (DEM; USGS seamless 10-m DEM) but is not always modeled at the exact global positioning system (GPS) coordinates. In those cases where the GPS locations did not align with the DEM-derived channel locations, the points were shifted to fall within the DEM-derivations for predictive modeling.
- Unless other information was provided, the rock gabion dams and earthen dams were modeled as uniform structures with a smooth overflow spillway spanning (1) the entire width of the structure for the rock gabion dams or (2) the width of the apparent channel for the earthen dams.
- The banks on each side of the rock gabion dams were assumed to lie at a 45° angle. This was used in the calculations to determine the width of the channel at the dam where the water would flow.
- The relations between depth of water in the detention ponds behind the dams and the discharge out of the dams were input to the model as a stage-discharge rating curve.

This information was derived from the 10-m DEM and the total dam height and includes total basin volume, total basin depth, and top and bottom surface areas. The DEM-derived storage and discharge from the modeling effort matched fairly well with what had been provided by IMIP, CONAGUA, and CILA (appendix A).

- Also, it is important to note that, judging from the photos of the Maquilas detention feature, it is filled nearly to the top with sediment and will not perform properly until it is cleaned out. We simulated it with its full design height of 4 m.

## 6.0 Results

A hydrograph depicts changes in the discharge of each arroyo/wash measured at the embankment dam over time; it is a representation of how a watershed responds to rainfall. The final hydrographs depicting each of the 10 locations (12 features) are available in appendix B. There are nine hydrographs for each location (six for Maquilas) that show the outflow with and without the dam and with different design storms so the effect of the dam can be visualized. These results were also summarized into a table (available in appendix B) describing the outflow in cubic meters, the peak flow in cubic meters per hour, and the sediment in kilograms for each scenario approximately 150 m downstream of the detention feature, and also describing the predicted difference the dam makes.

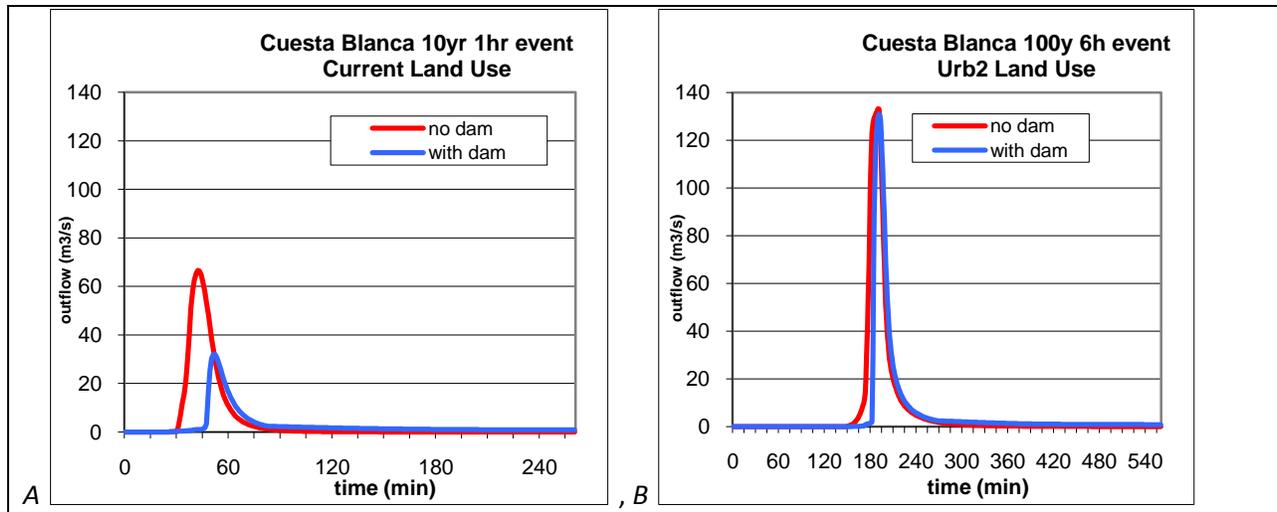
The hydrographs demonstrate temporal variability of runoff for the selected design storms (a 10-year 1-h (1.82 in.), a 25-year 6-h (2.93 in.), and a 100-year 6-h (3.76 in.)), as described earlier. The AGWA tool distributes rainfall uniformly over the watershed based on a synthetic hydrograph. This is distributed in two-minute time steps for the duration (that is, 6 hours), and the model is run for 200 minutes after rainfall ends.

For example, the rock gabion dam being constructed by the City known as Cuesta Blanca is pictured below in good maintenance (fig. 6).

Cuesta Blanca is one of the largest embankment dams in the sub-watershed and has the largest total storage of the rock-gabion types there. For a 10-year, 1-hour event, the volume of water stored behind the dam was calculated by the model to be approximately 60,000 cubic meters ( $m^3$ ; appendix B); this volume exceeds that of the other rock-gabions in the sub-watershed by more than 40,000  $m^3$ . In the 10-year, 1-hour event modeled using the current land-use scenario, the hydrograph shows that there is enough storage behind the dam to reduce peak flow by more than 50 percent and to delay the timing slightly (fig. 7A). In the 100-year, 6-hour event with the maximum urbanization (Urban 2) scenario, results show that because of the increased urbanization and consequent increase in runoff, there is a slight offset or delay in peak flow (long enough to fill the dam), but in a flood of this magnitude even the presence of this dam, largest of the rock gabions, has little effect on peak discharge (fig. 7B).



**Figure 6.** Photo of Represa Cuesta Blanca from upstream (Photograph by A. Prichard).



**Figure 7.** Hydrograph at the Cuesta Blanca detention feature showing results of simulating (A) a 10-year, 1-hour event in current land use scenario and (B) a 100-year, 6-hour event using the most urbanized scenario.

In general, the results shown in appendix B demonstrate that the detention features under current conditions of urbanization will reduce the peak flow slightly for the 10-year, 1-hour event but have less impact during the larger two storm events. When simulated with the increased urbanization scenarios, the detention features have little effect and provide only a

slight delay in peak flow (minutes) while storage behind the detention features is filled. Unsurprisingly, the most effective features are those that are larger in size.

The research identifies some potential impacts that could be felt at the border fence (watershed outlet). Without consideration of the interaction with other tributaries or land barriers, the maximum impacts of the features for tributaries analyzed in this study were summed based on current land use (table 2). These figures show:

- i) The total potential impact from installing the detention features of concern could reduce the total outflow from these locations by 19 percent in a 10-year, 1-hour event, by 15 percent in a 25-year, 6-hour event, and by 13 percent in a 100-year, 6-hour event,
- ii) the peak flow from these locations would be reduced by 46 percent in a 10-year, 1-hour event, by 44 percent in a 25-year, 6-hour event, and by 41 percent in a 100-year, 6-hour event, and
- iii) the sediment yield from these locations would be reduced by 61 percent in a 10-year, 1-hour event, by 61 percent in a 25-year, 6-hour event, and by 60 percent in a 100-year, 6-hour event.

**Table 2.** Summation of all results from the tributaries analyzed for current land use, showing the outflow, peak flow, and the sediment yield in a 10-year, 1-hour event, a 25-year, 6-hour event, and a 100-year, 6-hour event.

	Channel below dam	Outflow (m <sup>3</sup> )	Peak flow (mm/j t)	Sediment yield (kg)
10 year- 1 hour	w/out dam	477,136.59	549.71	44,064,895.50
	w/ dam	386,575.13	294.78	17,021,843.53
	<i>difference</i>	<i>90,561.46</i>	<i>254.93</i>	<i>27,043,051.97</i>
25 year- 6 hour	w/out dam	554,098.93	607.33	52,360,957.90
	w/ dam	471,640.89	337.97	20,173,279.62
	<i>difference</i>	<i>82,458.04</i>	<i>269.36</i>	<i>32,187,678.28</i>
100 year- 6 hour	w/out dam	938,204.12	926.64	106,436,249.70
	w/ dam	817,198.78	543.88	42,613,551.00
	<i>difference</i>	<i>121,005.33</i>	<i>382.76</i>	<i>63,822,698.70</i>

## 7.0 Caveats

### 7.1 Model Calibration and Potential Error

Accurately measured stream-flow data are essential for establishing whether a hydrologic model is providing reasonably accurate runoff estimates (Miller and others, 2002). In Ambos

Nogales, there are no flow gages for calibration and validation. Therefore, AGWA 2.0 results are best suited for relative change analysis or watershed-to-watershed comparisons (Goodrich and others, 2006). Like most models, AGWA 2.0 is also subject to the assumptions and limitations of its components, input data, and of course, its users. For example, soil saturation and geology are not included in this model, and soil type (clay, sand, or other) and precipitation (distribution of rainfall rates and locations) inputs are very low resolution. These are all factors that affect stream flow and would vary real-time measurements. In addition, the stage-discharge curves for the detention features were estimated on the basis of the 10-m DEM. Therefore the model-calculated storage volume and discharge may not reflect actual conditions. Because of this, the data shown above in table 2, and in appendix B, should be used as relative change estimates and not as absolute values.

## **7.2 Human Footprint**

People living within Nogales, Sonora, have affected the landscape as part of their everyday life. These anthropogenic manipulations are not included in the modeling effort, but they have significant effects on actual runoff.

### **7.2.1 Other Detention Features**

Many more detention features, or represas, were identified in the sub-watershed than were modeled in this study. Their absence from the model has consequences on the flood detention being estimated. For example, Cinco de Febrero is rumored to experience major flooding during monsoon but this detention feature was not included in this study (fig. 8).



**Figure 8.** Photo of the Respreso Cinco de Febrero. (Photograph by H.Huth.)

### 7.2.2 Maintenance of Detention Features

Detention features require regular maintenance to detain water in flood events. Maintenance includes clearing debris, sediment buildup, and dead vegetation, structural maintenance of stone rip-rap, and vegetation regeneration on adjacent hillslopes. Detention features cannot operate at full capacity if their maintenance is compromised (fig. 9).



**Figure 9.** Photo of Represa Las Piedras, which is backed up with sediment (left) and whose gabion is deteriorating. (Photograph by H. Huth.)

### 7.2.3 The “Periférico”

There are a number of features that have significant potential to alter flood peaks and flow routing that were only discovered by chance while traveling to survey known detention features. For example, there is a major highway being developed, the Periférico (a bypass around the city), which is not considered in this model. Large piles of dirt deposited in the canyons to accommodate the foundation for this road will act like earthen dams in the arroyo when it rains. Erosion and gully formation at the platform might deteriorate the structure and contribute to re-shaping the arroyo (fig. 10).



**Figure 10.** Photo of field team standing at the base of the Periférico, in front of a culvert. (Photograph by J. Callegary.)

Although planners have accommodated some potential flow at this location by developing the feature with a culvert (approximately 3 feet in diameter), it was observed to be half filled with sediment—before the monsoons had even arrived (fig. 11).

The potential effects of the earthen dams along the Periférico on flash flooding in the arroyos could be detention upstream and/or overflow that would affect the road, the arroyo, and the people downstream (fig. 12). These structures were not included in the modeling exercise described and therefore would need further study.



**Figure 11.** Photo of measurement in culvert (April 13, 2010) at arroyo under the Periférico. (Photograph by J. Callegary.)



**Figure 12.** Photo of Periférico acting as detention feature. (Photograph by H. Huth.)

**7.2.4 Other Water Conveyances Discovered During the Course of this Project**

The city, state, and country planning organizations have transportations networks historically routed in floodplains of the Nogales Wash (fig. 13). Some tunnels have been developed to route water under streets, and these features were not included in the model. One example is the culvert at Arroyo Cocodrilo (fig. 14), which splits downstream, sending some flow to the main branch of Nogales Wash (west branch) and some to the Grand Avenue tunnel (east branch). This information implies that the west branch drains a greater area than that delineated from the elevation data we used to derive our watershed, and this was not considered in this study. Other backyard fencing, buildings, stone walls, and ditch digging are also not included in this study but would have impacts on flow.



**Figure 13.** Photo of the start of Nogales Wash looking downstream (Photograph by H. Huth.)



**Figure 14.** Photo of culvert at Arroyo Cocodrilo. (Photograph by H. Huth.)

## 8.0 Conclusions

Floods resulting from convective precipitation (intense thunderstorms) are common in Ambos Nogales. The flooding exceeds the capacity of the river channel and endangers land areas used by many people. Although flood damage could be eliminated by moving buildings away from the Nogales Wash and its tributaries, the fact that people continue to inhabit areas threatened by flood damage is evidence that the perceived value of living downtown exceeds the cost of repeated periodic flooding. Effects of flooding include (a) physical damage (to, for example, bridges, houses, cars, buildings, sewer systems, roadways), (b) mortalities (for example, through drowning, epidemics, and waterborne disease), (c) contamination of water (limiting drinking water), (d) diseases (resulting from unhygienic conditions), (e) damage to vegetation (including crops), and (f) economic hardship (such as temporary decline in tourism and rebuilding costs).

The Nogales Wash is being studied to prevent flood disaster. The detention features being installed around the perimeter are a good starting defense but often are overwhelmed by flood water and require emergency measures such as pumping the detention ponds. The results of this modeling exercise will help land managers understand the impact of the detention features under various flood and urbanization scenarios. We demonstrate that detention features at current levels of urbanization will reduce the peak flow for the 10-year, 1-hour event but will have less

effect during the larger storm events or when under increased urbanization scenarios. More research to address some of the caveats associated with this study is described in the next section (Future Work).

In the summer of 2010, the 10-year events have caused emergency evacuation notices in Nogales, Arizona, and the state of Arizona declared a ‘state of emergency.’ Urbanization in Nogales is inevitable. It seems that a greater effort could be made to thwart danger associated with larger precipitation events in the future, especially for those people who do not have flood insurance. This may include investing in the construction of a more robust system of diversions, dikes, and floodways in Ambos Nogales, before the predicted population growth occurs.

## **9.0 Future Work**

### **9.1 LiDAR**

The application of high-spatial-resolution elevation data derived from light detection and ranging technologies (LiDAR) to surface hydrologic modeling could improve results. In recent years, airborne LiDAR technology has been employed to develop high accuracy digital elevation models (DEMs) with horizontal resolution on the order of a few meters. A LiDAR-derived DEM might better characterize flow direction, identify sub-basins, and calculate upstream contributing areas. Furthermore, a current LiDAR-derived DEM might help to map out detention features, tunnel entrances, bridges, walls, culverts, and other obstacles not included in a field survey. A LiDAR bid was acquired for the study area (appendix C).

### **9.2 Precipitation**

This modeling framework is being adapted to a larger “Early Warning Hazard System,” in which real-time precipitation data will be streamed into the existing model to estimate associated runoff (Project Chief, Floyd Gray). The Department of Defense’s Northern Command (NORCOMM) is funding the system to develop the most reliable alert system available. A rain gage network is being adapted in Nogales, Sonora, to measure precipitation and provide electronically recorded precipitation measurements straight to an online rainfall monitoring network initially developed for Nogales, Arizona (Rainlog.org). Gages will be well distributed throughout the upper watershed at Nogales, Sonora, to citizens of the community, drawing on collective local knowledge and support to determine the best locations. Members of the research team are recruiting residents who have Internet access and safe locations for the rain gages and electronic equipment to begin the process of receiving precipitation data and conveying it to the Rainlog Web site. Currently, one rain gage has been installed at the Nogales, Sonora, Water and Wastewater Utility. Information from this new station has been displayed online since April 5, 2010, and will be used to locate the most advantageous sites for larger, more extensive weather equipment (Norman, 2010; Norman and others, in press).

### **9.3 Field Measurements of Detention Features**

Field measurements to generate real-time hydrographs of discharge at the detention basins would better calibrate the model and improve results for this study area. This would require direct measurements of the stage for the duration of the flow, the storage of the basin, and periodic measurements of velocity to rate the stream and determine the relation of stage to discharge. Furthermore, the estimated infiltration of water at the detention basins would be valuable for calibrating the model and to facilitate groundwater recharge planning.

## 9.4 Water Quality

Finally, the issue of water quality or potential transfer of contaminants is not considered in this model. It was noted that industrial facilities in Nogales, Sonora, often discharge to the arroyos (fig. 15). Future research to investigate if contaminants in the channels are infiltrating and reaching the potable water supply is warranted.



**Figure 15.** Photo of Maquiladora discharge in Cuesta Blanca; pipes lead from industry to wash. (Photograph by H. Huth.)

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# Appendix A. Detention Feature Descriptions and Field Trip Notes

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## Kick-Off Meeting

The agenda (fig. 1) for the kick-off meeting included a presentation and the delivery of a worksheet (fig. 2) to all parties in attendance.

# **USGS Update on Watershed Modeling Efforts**

## **Meeting Location**

Santa Cruz Active Management Area  
Arizona Department of Water Resources Conference Room  
857 W. Bell Road, Suite 3, Nogales, Arizona 85621  
Phone: (520) 761-1814

January 19, 2010  
1 PM - 2 PM

**Goal:** Develop a stage-discharge curve for detention features

**Background:** The USGS, in cooperation with the University of Arizona, and Arizona Department of Environmental Quality are conducting a study for the IBWC/CILA on the impacts of the detention basins that have been constructed in Nogales, Sonora to help provide an understanding of the amount of water being detained by these features. We hope to provide information that can be used in planning flood management for the twin city area of Ambos Nogales.

In order to conduct this research within the model identified, we need to get measurements taken at each of the detention features that have been constructed. We have received a lot of the intended dimensions, but some of the basins have been constructed with changes based on their location and site conditions and so we need exact measurements to be taken of the features now. Even small variations in elevation and/or location can hurt the calculation tremendously.

Specifically we need GPS locations (Easting, Northing) as well as basin total volume, the total basin depth, top and bottom surface areas, and a description of any pipes (drainage) to be used to calculate the stage-discharge curve for input to model.

## **Tentative Agenda**

1:00 PM: Welcome and introductions (IBWC/CILA)

1:05 PM: Background on USGS Proposal and Modeling Efforts (Laura M. Norman, USGS).

1:20 PM: Summary of needs for "as-built" specifications for the detention features since they appear to differ from the plans shared with ADEQ and the USGS (Hans Huth, ADEQ and Lainie Levick, University of Arizona/U.S. Department of Agriculture).

1:40 PM: Questions from the audience and discussion as needed.

2:00 PM: Adjourn meeting.

**Figure 16.** Agenda for Kick-Off meeting

Nogales Detention Structures																		
Required Information		GPS Coordinates in UTM Zone 12, NAD 83																
Location of Dam			Description of Dam															
BASIN NAME	Easting or x-coord	Northing or y-coord	Outflow structure description	Spillway Dimensions	Dam Dimensions Overall Height	Dam Overall Width	Dam Overall Thickness	Dam Number of tiers	Width of tier 1	Height of tier 1	Width of tier 2	Height of tier 2	Width of tier 3	Height of tier 3	Width of tier 4	Height of tier 4	Width of tier 5	Height of tier 5
Example	505282.37	3457724.19	3-18" dia tubes at 2 ft above ground surface	10m x 1m	15 ft	25 ft	10 ft	5	1.5 ft.	1.5 ft								
Villa Sonora																		
Capulines																		
Cuesta Blanca																		
San Carlos Dique No. 1																		
San Carlos Dique No. 2																		
Bellotas Fraccionamiento																		
Bellotas Maquiladoras																		
Chimeneas																		
Represo Pirinola																		
Represo Unisom II																		
Represo Villa Sonora																		
Represo Chimineas																		

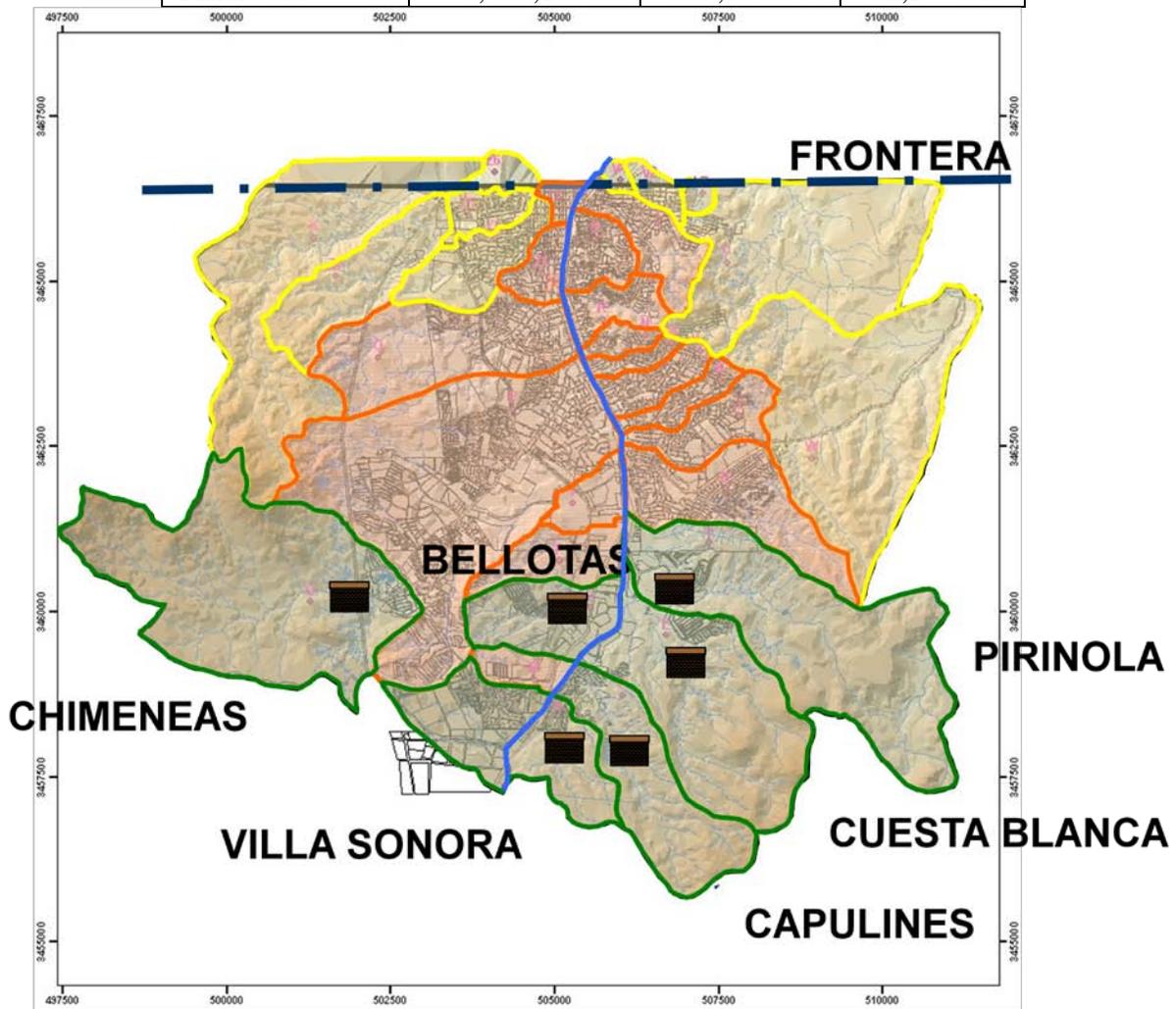
Figure 17. Worksheet for calculating needed measurements of the detention basins.

## Detention Feature Descriptions

Detention basins being constructed by the city include Chimeneas, Maquiladoras, Bellotas, Capulines, Cuesta Blanca [and San Carlos Dique No. 1 and No. 2, and Villa Sonora?]

**Table 3:** Coordinates of detention features (UTM, Zone 12, NAD83), provided by Claudia Gil and Monica Audelo.

Name	North	East	Elevation
BELLOTAS	3,459,900.26	504,653.926	1,294.904
MAQUILAS	3,460,203.452	505,261.884	1,270.754
CHIMENEAS	3,460,271.651	501,269.507	1,307.005
CAPULINES	3,457,709.952	505,925.154	1,297.844
CUESTA BLANCA	3,459,199.64	506,864.899	1,277.619



**Figure 18.** Map of detention features provided by Claudia Gil.

**Table 4:** Coordinates of Detention Features being considered (provided by Julio Luna Rodríguez and Claudia Gil).

San Carlos Dique No. 1	506825.37	3460198.55
San Carlos Dique No. 2	506984.06	3460126.51
Bellotas Fraccionamiento	504657.47	3459893.94

Stock Tanks being rehabilitated by CONAGUA, including: Represo Chimineas, Represo Pirinola, Represo Villa Sonora, and Represo Unison II.

**Table 5:** Measurements of rehabilitated detention features provided by Ing Gilberto Patricio Olivero Granillo (Coordinador del FONDEN and contracted by CONAGUA)

Represos	Latitude	Longitude	Available Capacity (cubic meters)	Current Volume (cubic meters)	Altitude (m)	Monthly precip (mm)	Annual precip (mm)	CSA (sq. kilometers)	Watershed #
Pirinola	31.274444	110.911111	748,475.00	9,708.75	1,316	200	700	6.11	16
Chimineas	31.276667	110.974167	797,343.75	32,157.17	1,284	175	625	7.29	17
Villa Sonora	31.253611	110.944444	99,750.00	1,275.60	1,315	100	500	1.33	7
Unison II	31.235278	110.926667	345,870.00	4,114.25	1,427	120	540	4.27	14

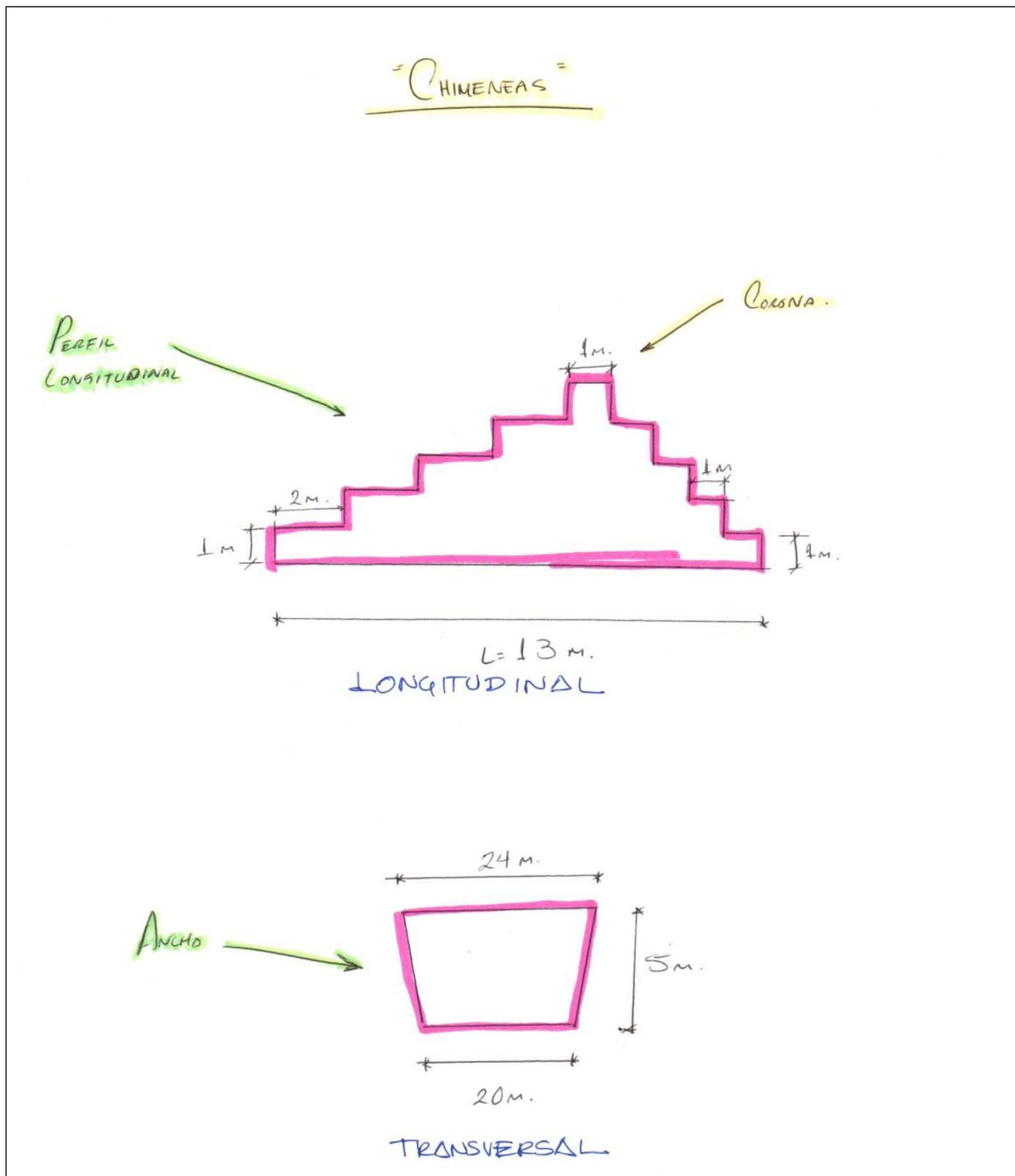
## **Trip # 1**

Andrea Harrop Prichard and Prescott Vandervoet from the University of Arizona, Udall Center for Studies in Public Policy are researchers for the Transboundary Aquifer Assessment Program (TAAP) who helped acquire data for this project.

On March 24, 2010 they met with Ing. Claudia Gil. Claudia reports that 5 detention features have been constructed, although the smallest one is not very useful because new development has rerouted the water so it no longer passes through. When University researchers arrived to OOMAPAS, they were greeted by a large group of engineers and technicians (about 9) who provided tremendous guidance and assistance to our team.

## **Chimeneas**

Chimeneas is the largest represo, but it is unfinished. Claudia reports that it has been in operation since April of 2009, so it has undergone a monsoon season, albeit a relatively weak one. She also told researchers that the designer of these structures, Ing. Julio Luna Rodriguez, is a civil engineer from the University of Sonora. Once drafted the plans were sent through CONAGUA and modified before implementation. Claudia also reports that plans for the Chimeneas to contain a vertedor, or notch in the top of the feature (to channel floodwater to prevent bank erosion) were scratched by CONAGUA. She also reports that a cama de amortiguamiento (a gabion structure on the ground level on the downstream side), used to prevent undercutting in a sediment-filled channel, was planned but not completed for the Chimeneas represo. Staff from IMIP showed the TAAP researchers that the cortina (gabion blocks) were unfinished on the downstream side. It is designed to be kind of a pyramid/step-ladder shape, but estimated 3 (out of 5) of those layers are not present on the downstream side. IMIP is waiting for funding for the completion of the design, but it does seem to be up and working nonetheless.



**Figure 19:** Diagram of Represo Chimineas provided by Claudia Gil.

Measurements:

Length of bottom of detention Feature: 56 feet

Length of top of detention Feature: 82 feet 6 inches



**Figure 20.** Photo of Chimeneas Entrance Gate and Well (A. Prichard)



**Figure 21.** Photo of Chimeneas View from Upstream (A. Prichard)



**Figure 22.** Photo of Chimeneas Upstream North Bank (A. Prichard)



**Figure 23.** Photo of Chimeneas Organic Soil Upstream (A. Prichard)



**Figure 24.** Photo of Chimeneas Organic Buildup Upstream (A. Prichard)



**Figure 25.** Photo of Chimeneas View Upstream of Feature (A. Prichard)



**Figure 26.** Photo of Chimeneas (A. Prichard)



**Figure 27.** Photo of Chimeneas Upstream South Bank (A. Prichard)



**Figure 28.** Photo of Chimeneas Length To Bank at 3m height(South) (A. Prichard)



**Figure 29.** Photo of Chimeneas View from top of Gabion pyramid (A. Prichard)



**Figure 30.** Photo of Chimeneas (A. Prichard)



**Figure 31.** Photo of Chimeneas (A. Prichard)



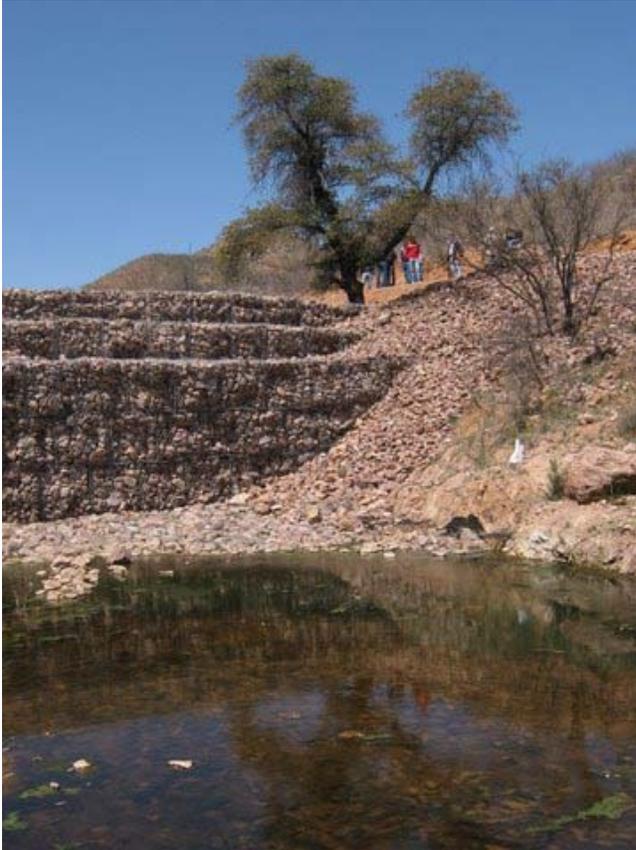
**Figure 32.** Photo of Chimeneas Length To Bank at 3m height (North) (A. Prichard)



**Figure 33.** Photo of Chimeneas View from Downstream (A. Prichard)



**Figure 34.** Photo of Chimeneas View from Downstream-SouthSide (A. Prichard)



**Figure 35.** Photo of Chimeneas View from Downstream - NorthSide (A. Prichard)



**Figure 36.** Photo of Chimeneas DirtBank (A. Prichard)



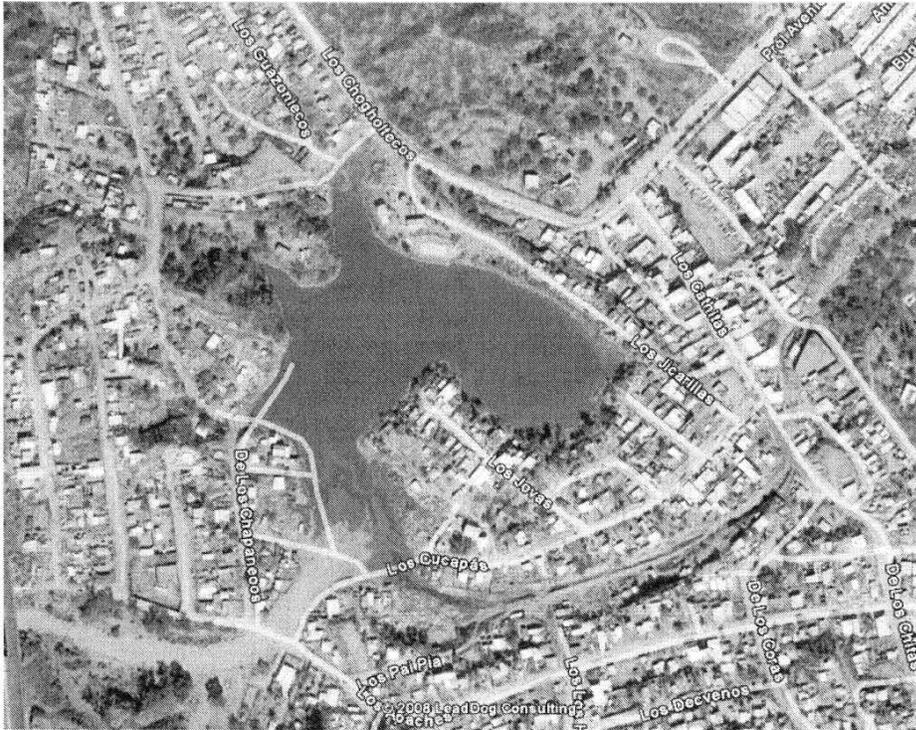
**Figure 37.** Photo of Chimeneas Downstream View from Feature - SouthBank (A. Prichard)



**Figure 38.** Photo of Chimeneas Downstream view From Feature – NorthBank (A. Prichard)

## Represo Chimineas

### MICROLOCALIZACION DEL REPRESO CHIMINEAS



Ubicación con Coordenadas:

31°16'46 N

110°58'27 O

Altitud de 1284.00 mts. sobre el nivel del mar.

El vertedor cuenta con la siguiente ubicación:

31°16'36 N

110°58'27 O

Altitud de 1284.00 mts. sobre el nivel del mar.

El área correspondiente a este represo es la cuenca 17 de 7.29 km<sup>2</sup>.

Precipitación mensual de la cuenca: 175 mm

Precipitación anual de la cuenca: 625 mm

Volumen Escurrido Probable: 797,343.75 m<sup>3</sup> ✓

Capacidad actual del represo: 32,157.17 m<sup>3</sup>

El banco de préstamo de material esta localizado en la misma ubicación del represo.

**Figure 39.** Information describing Represo Chimineas provided by Ing. Gilberto Patricio Olivero Granillo.



**Figure 40.** Photo of Represo Chimineas view of the dam from upstream with the hillside on both ends (A. Prichard).



**Figure 41.** Photo of Represo Chimineas view of the dam from upstream with the hillside on both ends (A. Prichard).



**Figure 42.** Photo of Represo Chimineas view of the dam from upstream with the hillside on both ends (A. Prichard).



**Figure 43.** Photo of Represo Chimineas view upstream from the dam including the right side of the channel (A. Prichard).



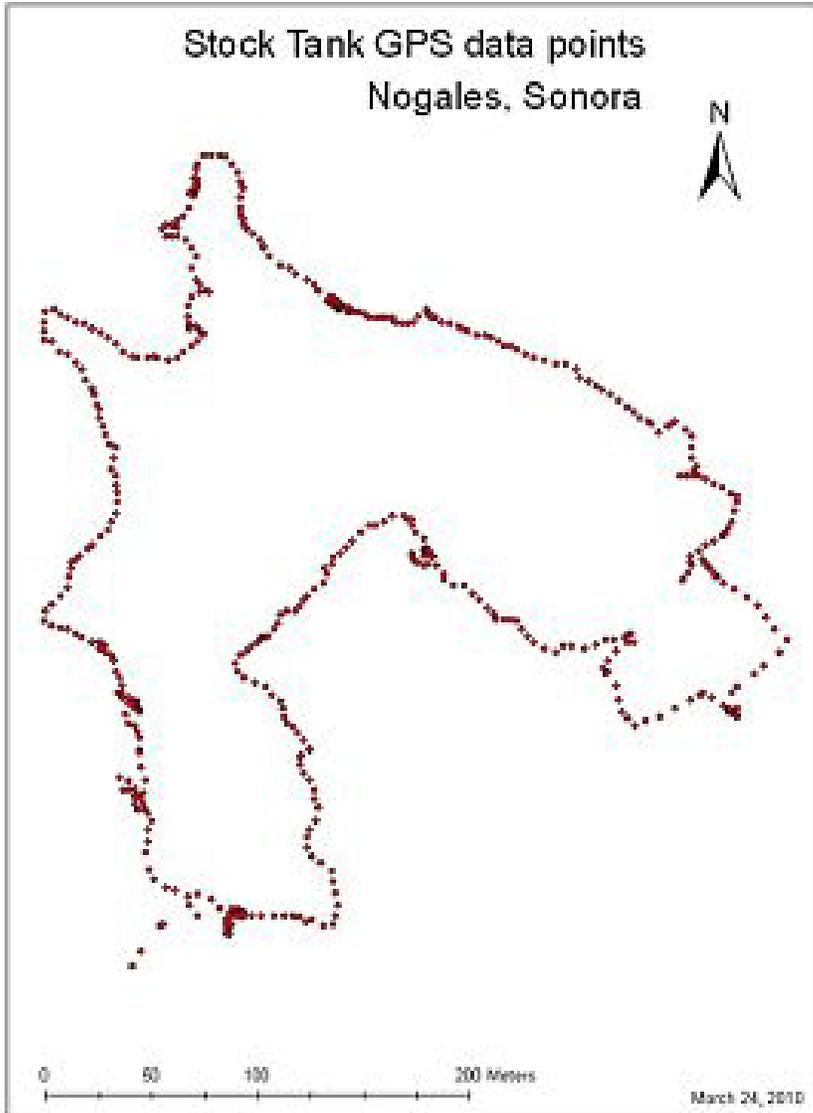
**Figure 44.** Photo of Represo Chimineas view upstream from the dam including the right side of the channel (A. Prichard).



**Figure 45.** Photo of Represo Chimineas view upstream from the dam including the left side of the channel (A. Prichard).



**Figure 46.** Photo of Represo Chimineas view upstream from the dam including the left side of the channel (A. Prichard).



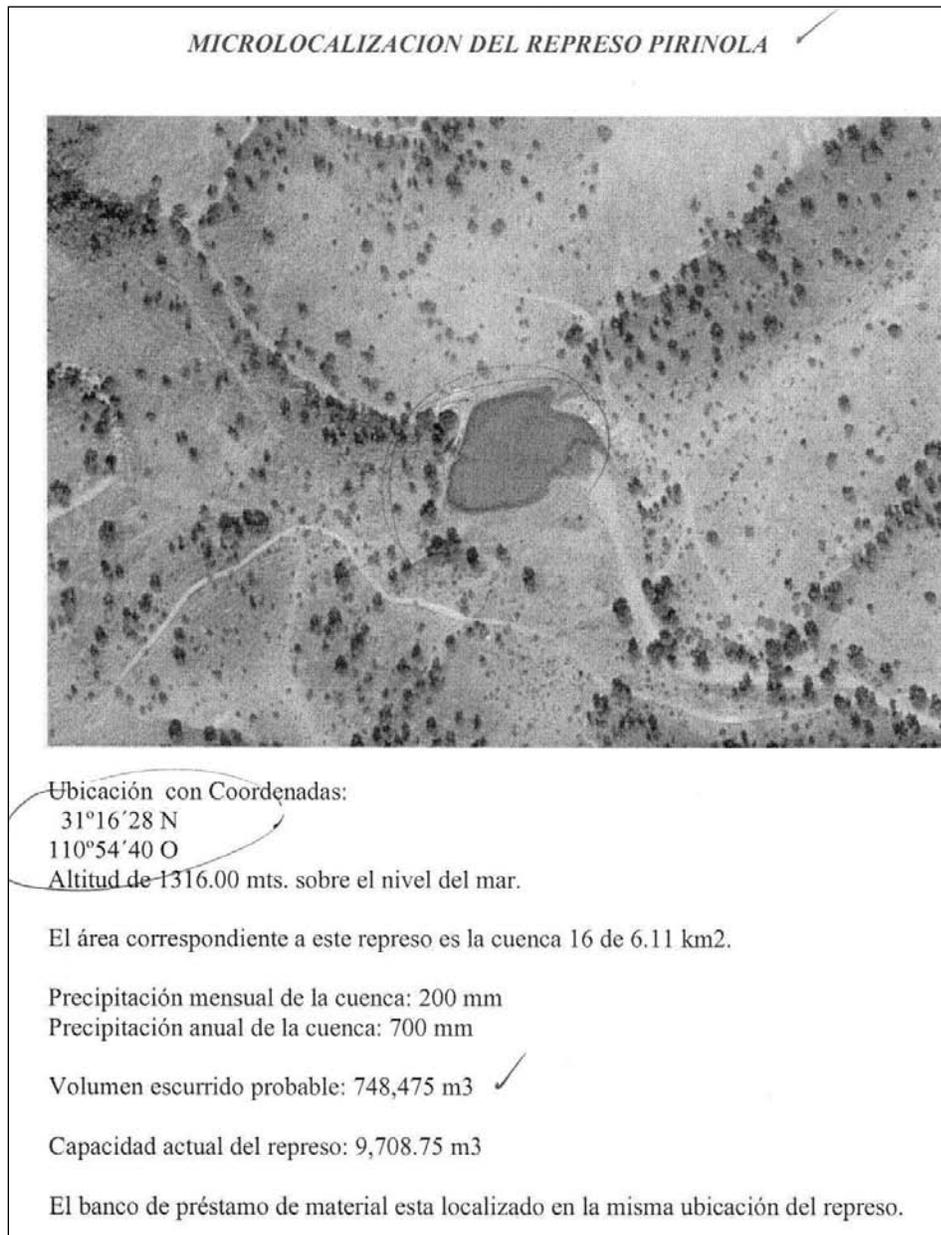
**Figure 47.** Stock Tank TRACK, 2010-04-20, map by Andrea Prichard.

### **Trip #2**

James Callegary and Floyd Gray (USGS), and Hans Huth (Arizona Department of Environmental Quality) went to Nogales on Tuesday, April 13, 2010.

Jesus Quintanar facilitated the visit. Ing. Claudia Gil helped with the visit with Edgar Castellanos and Edgar Tepezano. The tour took place on April 13 and included a review of stormwater conveyance infrastructure; installation of internet accessible raingages purchased by the USGS under a Department of Defense Northern Command grant; review of potential sites for installation of stream gages in Nogales, Sonora; visits to several detention features facilitated in part with monies from the EPA Border 2012 Program; and review of potential sites for installation of two weather monitoring stations for capture of incoming weather.

## Represo Pirinola (a.k.a. Centauro Dam)



**Figure 48.** Information describing Represo Pirinola provided by Ing Gilberto Patricio Olivero Granillo.



**Figure 49.** Photo of Represo Pirinola panoramic looking upstream from left to right (H. Huth).



**Figure 50.** Photo of Represo Pirinola panoramic looking upstream from left to right (H. Huth).



**Figure 51.** Photo of Represo Pirinola panoramic looking upstream from left to right (H. Huth).



**Figure 52.** Photo of Represo Pirinola panoramic looking upstream from right to left (H. Huth).



**Figure 53.** Photo of Represo Pirinola looking from left bank to right bank along feature (H. Huth).



**Figure 54.** Photo of Represo Pirinola looking downstream (H. Huth).



**Figure 55.** Photo of Represo Pirinola on left bank looking upstream (H. Huth).



**Figure 56.** Photo of Represo Pirinola on right bank looking towards left bank. Hans Huth.



**Figure 57.** Photo of Represo Pirinola on feature looking upstream and to the right (H. Huth).



**Figure 58.** Photo of Represo Pirinola on middle of feature looking towards the left (H. Huth).



**Figure 59.** Photo of Represo Pirinola on middle of feature looking down (H. Huth).

### **Trip #3**

Floyd Gray and Andrea Prichard made a field trip to Nogales, Sonora on Wednesday, May 19th with Ing. Gil, Quintanar, Rodriguez, Tepezano, and Castellanos.



**Figure 60.** Photo of field trip; group picture (from left to right): Jesus Quintanar, Claudia Gil, Floyd Gray, Saul Rodriguez, Andrea Prichard, Edgar Castellanos, Edgar Tepezano (A. Prichard).



**Figure 61.** Engineers from IMIP: Edgar Castellanos and Edgar Tepezano (A. Prichard).

Maquiladoras (a.k.a. Maquillas)

REPRESO MAQUILLAS

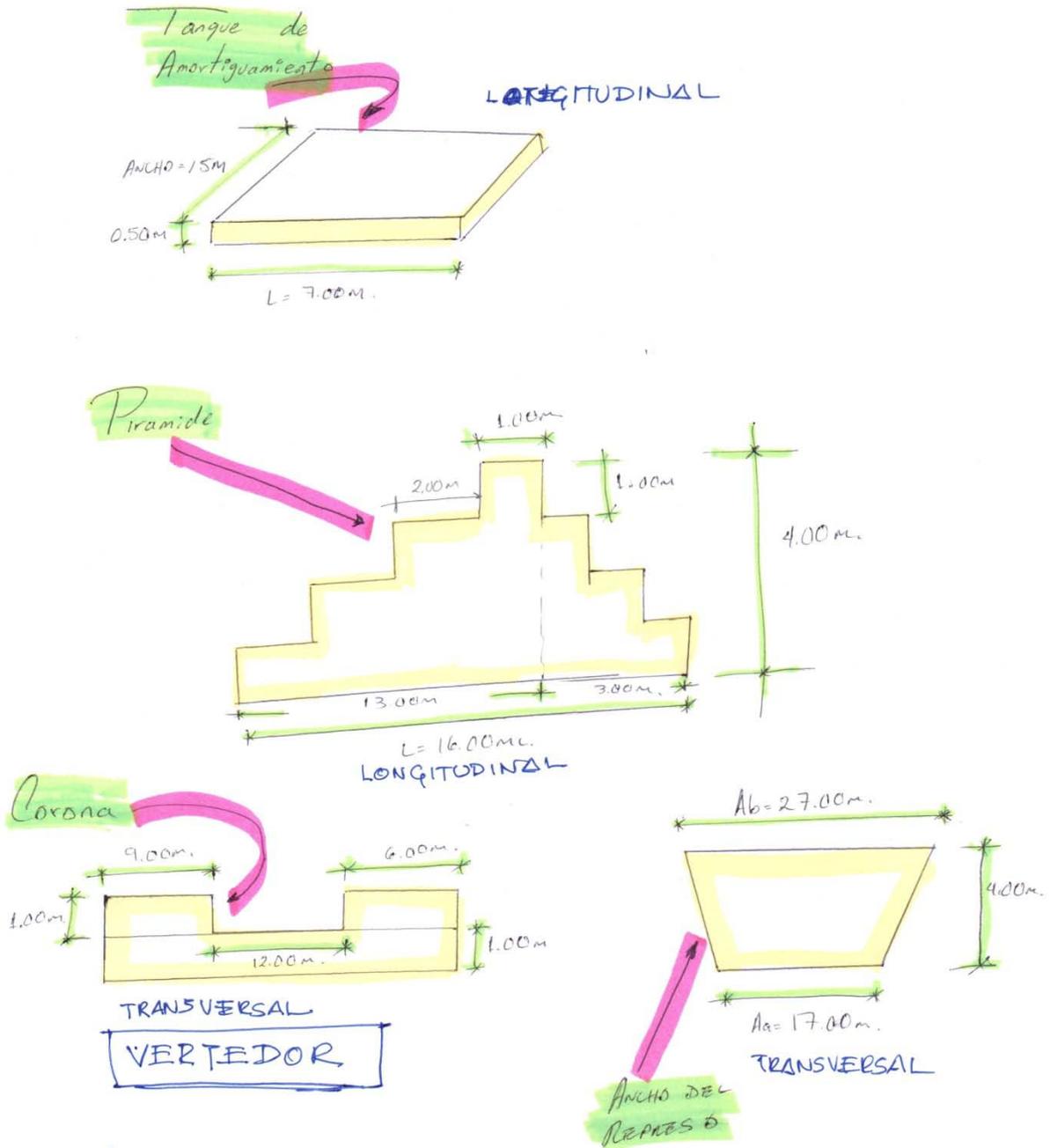


Figure 62. Diagram of Represo Maquillas provided by Claudia Gil.



**Figure 63.** Photo of Represo Maquilas From Upstream (A. Prichard).



**Figure 64.** Photo of Represo Maquilas Sidewall (A. Prichard).



**Figure 65.** Photo of Represo Maquilas Manhole (A. Prichard).



**Figure 66.** Photo of Represo Maquilas (A. Prichard).



**Figure 67.** Photo of Represo Maquilas looking upstream, southside (A. Prichard).



**Figure 68.** Photo of Represo Maquilas looking upstream, northside (A. Prichard).



**Figure 69.** Photo of Represo Maquilas looking downstream, northside (A. Prichard).



**Figure 70.** Photo of Represo Maquilas looking downstream, southside (A. Prichard).



**Figure 71.** Photo of Represo Maquilas From Downstream (A. Prichard).



**Figure 72.** Photo of Represo Maquilas from Downstream, South Side (A. Prichard).



**Figure 73.** Photo of Represo Maquilas from the East (A. Prichard).



**Figure 74.** Photo of Represo Maquilas Looking Downstream, Southside (A. Prichard).



**Figure 75.** Photo of Represo Maquilas (A. Prichard).



**Figure 76.** Photo of Represo Maquilas Looking Downstream, NorthSide (A. Prichard).



**Figure 77.** Photo of Represo Maquilas Parking (A. Prichard).



**Figure 78.** Photo of Represo Maquilas Damaged Gabion (A. Prichard).



**Figure 79.** Photo of Represo Maquilas entrance to Structure (A. Prichard).



**Figure 80.** Photo of Represo Maquilas damaged gabion Wall (A. Prichard).



**Figure 81.** Photo of Represo Maquilas damaged gabion East of tunnel (A. Prichard).



**Figure 82.** Photo of Represo Maquilas tunnel, approximately 200m West of dam (A. Prichard).

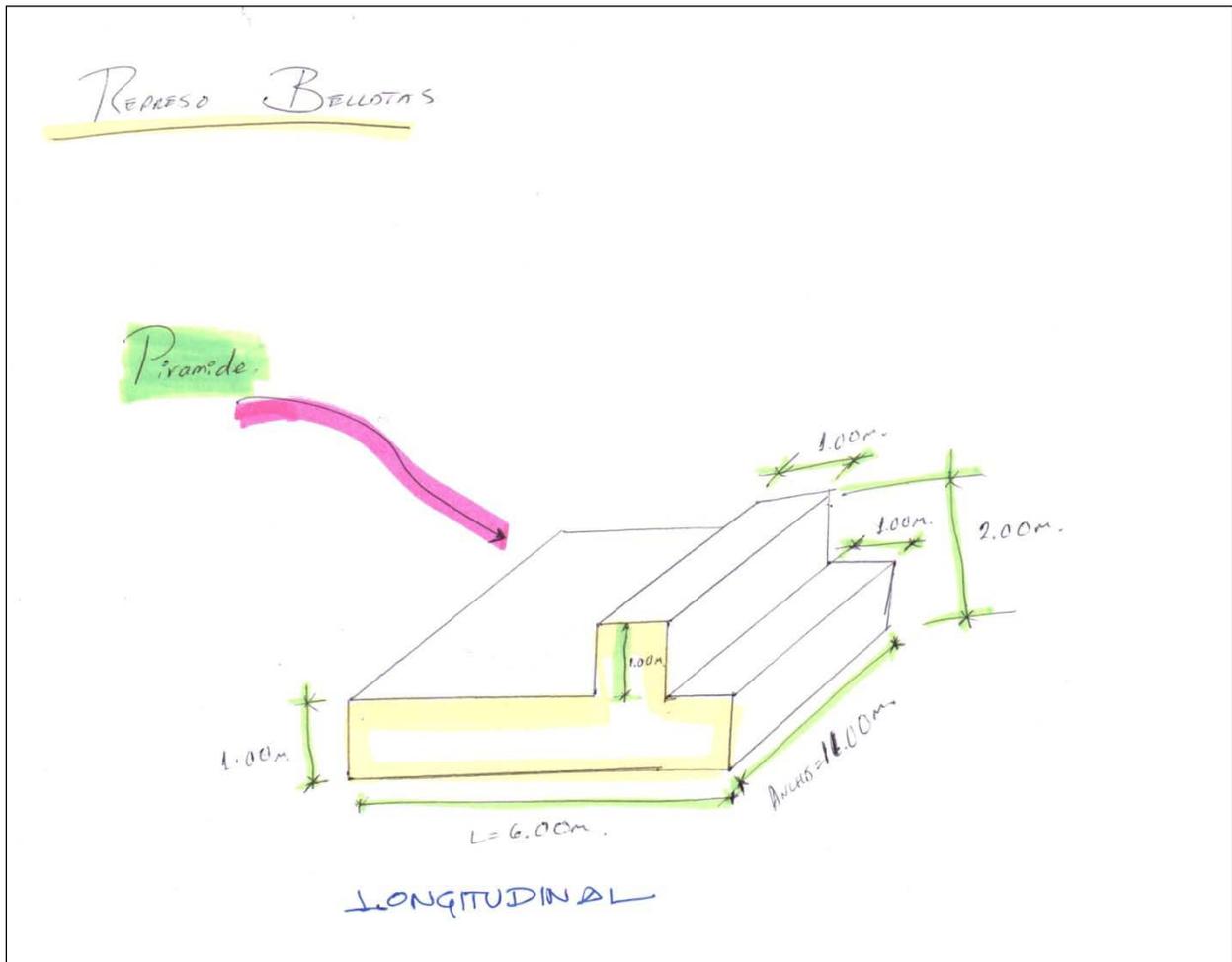


**Figure 83.** Photo of Represo Maquilas Looking East from Tunnel (A. Prichard).



**Figure 84.** Photo of Represo Maquilas looking East from top (A. Prichard).

## Bellotas



**Figure 85.** Diagram of Represo Bellotas provided by Claudia Gil

The represo is a small structure (2 m high, 10-11m across). Due to recent development, water flows have been diverted to a nearby road parallel to the stream causing the represo to be less effective. Water flows from the NW to SE direction while the represo structure is situated NE to SW.



**Figure 86.** Photo from Represo Bellotas from Downstream (SE) (A. Prichard).



**Figure 87.** Photo from Represo Bellotas from Downstream, SW side (A. Prichard).



**Figure 88.** Photo from Represo Bellotas From Downstream, NE side (A. Prichard).



**Figure 89.** Photo from Represo Bellotas Looking Downstream, NEside (A. Prichard).



**Figure 90.** Photo from Represo Bellotas Looking Downstream, SWside (A. Prichard).



**Figure 91.** Photo from Represo Bellotas Looking Upstream, SW side (A. Prichard).



**Figure 92.** Photo from Represo Bellotas Looking Upstream, NE side (A. Prichard).



**Figure 93.** Photo from Represo Bellotas from Upstream (A. Prichard).



**Figure 94.** Photo from Represo Bellotas from Upstream, SW side (A. Prichard).



**Figure 95.** Photo from Represo Bellotas from Upstream, NEside (A. Prichard).



**Figure 96.** Photo from Represo Bellotas Parallel Street, new Developments (A. Prichard).

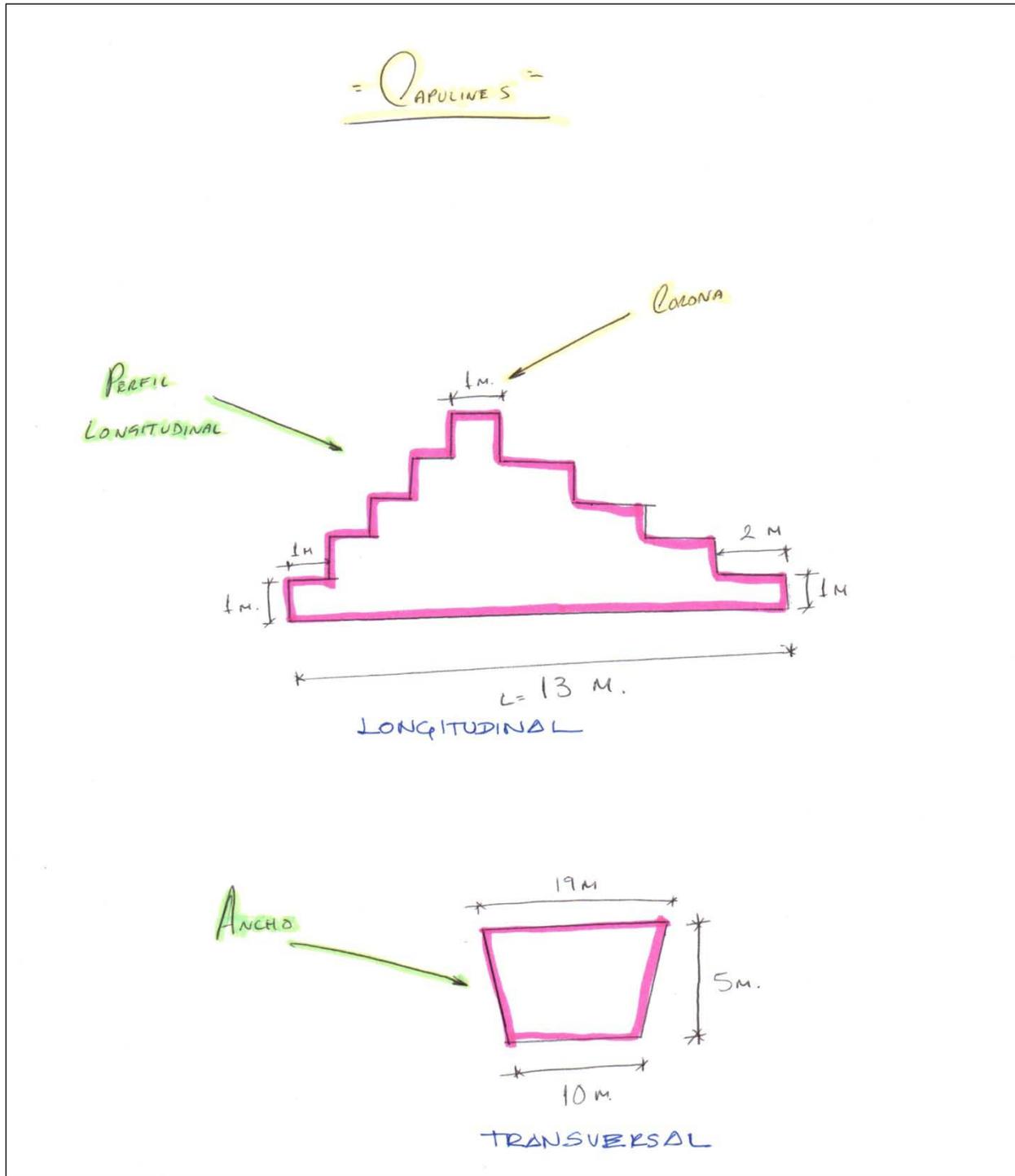


**Figure 97.** Photo from Represo Bellotas from Street, looking at Trucks and dam (A. Prichard).



**Figure 98.** Photo from Represo Bellotas Street, looking upstream ; water flows here instead (A. Prichard).

# Capulines



**Figure 99:** Diagram of Repeso Capulines provided by Claudia Gil.



**Figure 100.** Photo of Represo Capulines from North (A. Prichard).



**Figure 101.** Photo of Represo Capulines from Downstream, EastSide (A. Prichard).



**Figure 102.** Photo of Represo Capulines from Downstream, WestSide (A. Prichard).



**Figure 103.** Photo of Represo Capulines Looking Downstream, EastSide (A. Prichard).



**Figure 104.** Photo of Represo Capulines Looking Downstream, West Side (A. Prichard).



**Figure 105.** Photo of Represo Capulines looking Upstream, East Side (A. Prichard).



**Figure 106.** Photo of Represo Capulines Looking Upstream, WestSide (A. Prichard).



**Figure 107.** Photo from Represo Capulines looking South from top (A. Prichard).



**Figure 108.** Photo of Represo Capulines Looking Upstream (A. Prichard).



**Figure 109.** Photo of Represo Capulines Looking Downstream, Capulines (A. Prichard).



**Figure 110.** Photo of Represo Capulines From Upstream, WestSide (A. Prichard).



**Figure 111.** Photo of Represo Capulines From Upstream, EastSide (A. Prichard).



**Figure 112.** Photo of Represo Capulines From Upstream (A. Prichard).



**Figure 113.** Photo approx. 75 m. south of Represo Capulines of Canyon and Waterfall (A. Prichard).

## Represo Villa Sonora

### *MICROLOCALIZACION DEL REPRESO VILLA SONORA*



Ubicación con Coordenadas:

31°15'13 N

110°56'40 O

Altitud de 1315.00 mts. sobre el nivel del mar.

El área correspondiente a este represo es la cuenca 7 de 1.33 km<sup>2</sup>.

Precipitación mensual de la cuenca: 100 mm

Precipitación anual de la cuenca: 500 mm

Volumen escurrido probable: 99,750 m<sup>3</sup> ✓

Capacidad actual del represo: 1,275.60 m<sup>3</sup>

El banco de préstamo de material esta localizado en la misma ubicación del represo.

**Figure 114.** Information describing Represo Villa Sonora provided by Ing Gilberto Patricio Olivero Granillo.

Represo Villa Sonora looks like a dry, mudcracked pond that is emptied through a notch in the earthen dam into a narrow, steep rocky stream. It was constructed a long time ago to form a create water storage for livestock. There are plans to both raise the height to approximately 8m, and to rehabilitate the dam with a new concrete barrier.



**Figure 115.** Photo of Represo Villa Sonora hole Looking Downstream (A. Prichard).



**Figure 116.** Photo of Represo Villa Sonora Looking Upstream (A. Prichard).



**Figure 117.** Photo of Represo Villa Sonora looking West(downhill) (A. Prichard).



**Figure 118.** Photo of water behind Represo Villa Sonora (A. Prichard).



**Figure 119.** Photo of Represo Villa Sonora (A. Prichard).



**Figure 120.** Photo of Represo Villa Sonora from Below Hole (A. Prichard).



**Figure 121.** Photo of Represo Villa Sonora Creek Downstream (A. Prichard).



**Figure 122.** Photo of Represo Villa Sonora (A. Prichard).



**Figure 123.** Photo of Represo Villa Sonora volcanic rock (A. Prichard).

## Represo Unison II

### *MICROLOCALIZACION DEL REPRESO UNISON II*



Ubicación con Coordenadas:

31°14'07 N

110°55'36 O

Altitud de 1427.00 mts. sobre el nivel del mar.

El área correspondiente a este represo es la cuenca 14 de 4.27 km<sup>2</sup>.

Precipitación mensual de la cuenca: 120 mm

Precipitación anual de la cuenca: 540 mm

Volumen escurrido probable: 345,870 m<sup>3</sup> ✓

Capacidad actual del represo: 4,114.25 m<sup>3</sup>

El banco de préstamo de material esta localizado en la misma ubicación del represo.

**Figure 124.** Information describing Represo Unison II provided by Ing Gilberto Patricio Olivero Granillo.

This is a large earthen dam, also slated to be raised to about 8 m.



**Figure 125.** Photo of Represo Unison II from NW (A. Prichard).



**Figure 126.** Photo of Represo Unison II creek entering dam from West (A. Prichard).



**Figure 127.** Photo of Represo Unison II on SW (A. Prichard).



**Figure 128.** Photo of Represo Unison II Looking Downstream(S) (A. Prichard).



**Figure 129.** Photo of Represo Unison II Looking North (A. Prichard).



**Figure 130.** Photo of Represo Unison II Looking NE (A. Prichard).



**Figure 131.** Photo of Represo Unison II Looking NW (upstream) (A. Prichard).



**Figure 132.** Photo of Represo Unison II (A. Prichard).



**Figure 133.** Photo of Represo Unison II Rock Outcrop (A. Prichard).



**Figure 134.** Photo of Represo Unison II from Downstream (A. Prichard).



**Figure 135.** Photo of Represo Unison II Creek Downstream (A. Prichard).

Cuesta Blanca

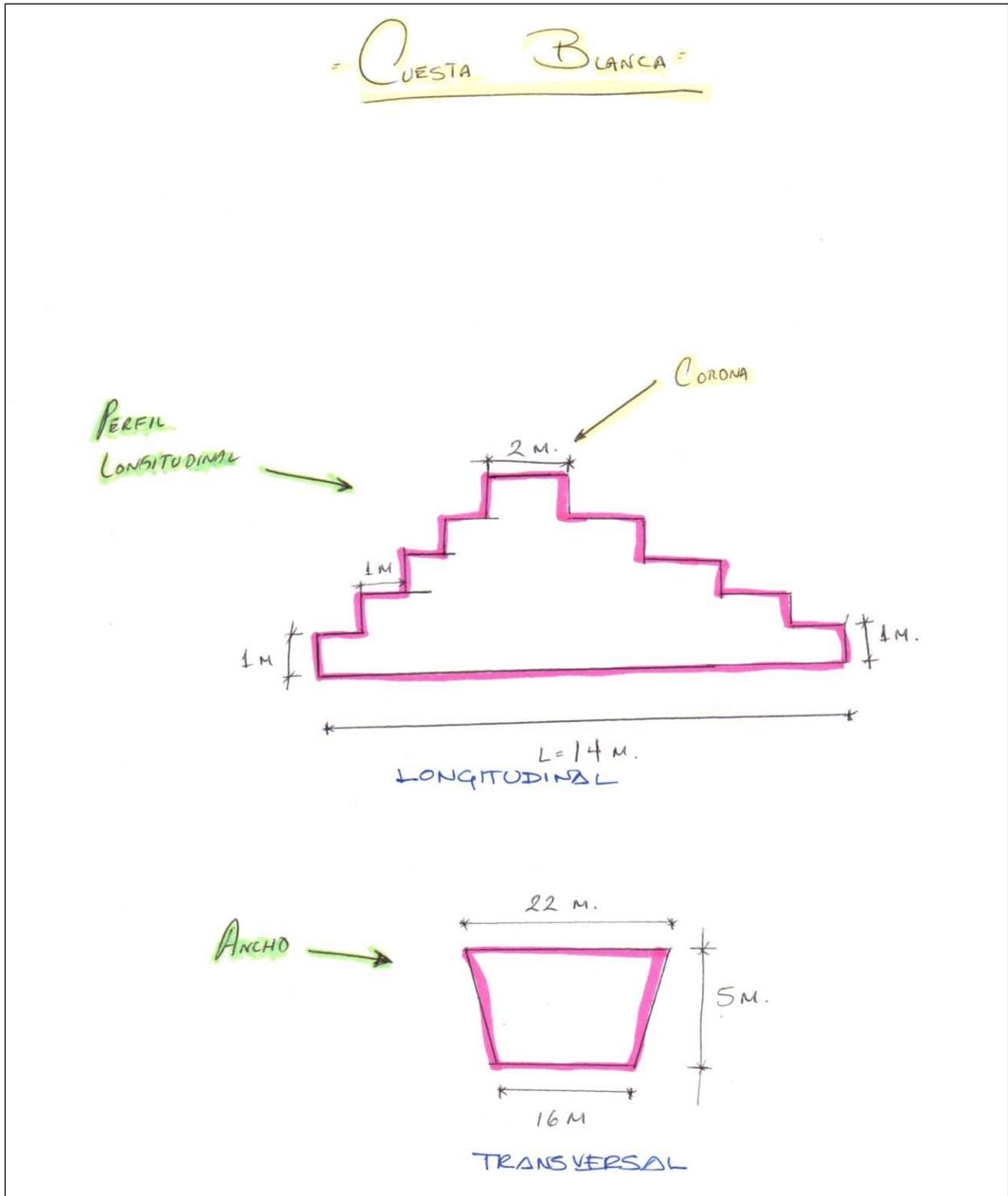


Figure 136. Diagram of Represo Cuesta Blanca provided by Claudia Gil.



**Figure 137.** Photo of Represo Cuesta Blanca bank downstream (A. Prichard).



**Figure 138.** Photo of Represo Cuesta Blanca Rocks (A. Prichard).



**Figure 139.** Photo of Represo Cuesta Blanca from Downstream (A. Prichard).



**Figure 140.** Photo of Represo Cuesta Blanca from Downstream, South Side (A. Prichard).



**Figure 141.** Photo of Represo Cuesta Blanca from Downstream, NorthSide (A. Prichard).



**Figure 142.** Photo of Represo Cuesta Blanca Looking Downstream, SouthSide (A. Prichard).



**Figure 143.** Photo of Represo Cuesta Blanca Looking Downstream, NorthSide (A. Prichard).



**Figure 144.** Photo of Represo Cuesta Blanca Looking Upstream, South Side (A. Prichard).



**Figure 145.** Photo of Represo Cuesta Blanca Looking Upstream, NorthSide (A. Prichard).



**Figure 146.** Photo of Represo Cuesta Blanca from Upstream, South Side (A. Prichard).



**Figure 147.** Photo of Represo Cuesta Blanca from Upstream, NorthSide (A. Prichard).



**Figure 148.** Photo of Represo Cuesta Blanca from Upstream (A. Prichard).



**Figure 149.** Photo of Represo Cuesta Blanca Gabions (A. Prichard).



**Figure 150.** Photo of Represo Cuesta Blanca Gabions (A. Prichard).



**Figure 151.** Photo of Represo Cuesta Blanca community, San Carlos (A. Prichard).

## **Appendix B. Detailed Results from the Study**

This Appendix consists of a set of spreadsheet files. They are in this linked spreadsheet folder:  
*[http://pubs.usgs.gov/of/2010/1262/of2010-1262\\_appendix\\_b/](http://pubs.usgs.gov/of/2010/1262/of2010-1262_appendix_b/)*

**APPENDIX C. Laser Mapping quote for Nogales, Mexico**  
(Matthew Coleman, Airborne 1 Corporation, phone (310) 414-7400 x261,  
coleman@airborne1.com)



4/21/2010

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**LiDAR Cost Estimate for Nogales, Sonora,  
Mexico**

(approx. 18,121 acres)

*Prepared for USGS*

**Services and Costs**

Airborne 1 Corporation will provide a Digital Elevation Model (DEM) in ASCII X Y Z format. This data will typically be collected using an Optech ALTM 3100(EA) LiDAR System collecting 33,000 – 100,000 multiple return measurements per second.

**High Resolution – Vertical accuracy of 95% at 0.6' (<18.5cm) and 90% at 0.5' (15cm), horizontal accuracy of 1.0' (30cm), 1 sigma.**

Project Initiation & Asset/Resource Commitment.....	\$3,500*
Ferry (410 nautical miles from Burbank, CA).....	\$9,700*
Collect & Process, including GPS ground control & QC.....	\$15,300
<b>Total price including ground survey.....</b>	<b>\$28,500</b>

*\*Please note that the mobilization fees are firm fixed fees using our best logistical knowledge on the proposal creation date. Airborne 1 assumes all risk on these prices.*

1. Prices are subject to change without notice.
2. The above price summary does not constitute as a commitment or contract. A formal proposal will be required finalize terms, conditions, and deliverables.