Understanding Sediment Processes of Los Laureles Canyon in the Binational Tijuana River Watershed

Presenter: Yongping Yuan, Ph.D, Research Hydrologist; USEPA-Office of Research and Development,

Environmental Sciences Division, Las Vegas, NV 89119; Tel: 702-798-2112; E-mail: yuan.yongping@epa.gov

RESEARCH TEAM

Pictured left to right:
Dr. Carlos Castillo, University of Cordoba
Dr. Encarnacion Taguas, University of Cordoba
Dr. Yongping Yuan, USEPA - Office of Research and Development
Dr. Ron Bingner, USDA-Agricultural Research Services
Napoleón Gudiño, post-graduate, Ensenada Center for Scientific Research and Higher Education
Kristine Taniguchi, post-graduate, San Diego State University
Dr. Eddy Langendoen, USDA-Agricultural Research Services
Dr. Trent Biggs, San Diego State University
Doug Liden, USEPA – Region 9;
Dr. Cindy Lin, USEPA Region 9 (not pictured).

ABSTRACT

Tijuana River Basin originates in Mexico and drains 4465 km^2 into the Tijuana River Estuary National Research Reserve, a protected coastal wetland in California that supports 400 species of birds. During storms, excessive erosion in Tijuana produces sediment loads that bury native vegetation and block the tidal channels. It also threatens human life, causing roads and houses in Mexico to collapse and the Tijuana River Valley in the U.S. to flood; government agencies in US and Mexico spend millions annually to remove sediment. The US Environment Protection Agency (USEPA)-SEMARNAT Border 2020 program made reducing sediment to the Tijuana Estuary a high priority. The primary sources of sediment are gully formation on unpaved roads, channel erosion, and sheet and rill erosion from vacant lots in Tijuana (Biggs et al, 2009). Because 73% of the watershed is located in Mexico, the problem is likely to worsen as Tijuana continues to urbanize. USEPA, with support from US Department of Agriculture (USDA), San Diego State University (SDSU), and Ensenada Center for Scientific Research and Higher Education (CICESE), is collecting data to develop a model that estimates sediment loadings in a sub-basin of the watershed (Los Laureles Canyon) for existing conditions as well as future alternative development scenarios. This study also evaluates reduction/prevention of sediment loads from green infrastructure projects, sediment basins, road paving, and conservation easements; the Annualized AGricultural Non-Point Source (AnnAGNPS) and CONservational Channel Evolution and Pollutant Transport System (CONCEPTS) models were used. USEPA/SDSU/USDA/CICESE personnel have conducted or are conducting: 1) rainfall, runoff and sediment monitoring to understand the hydrologic and sediment processes; 2) field sampling to determine channel stability and its contribution to the sediment budget of the study watershed; 3) gully mapping and topographic surveys following storm events to understand gully formation and evolvement; 4) bed and bank material characterization and mapping. Workshops/training on field data collection and model development are ongoing efforts to keep National Water Commission (CONAGUA), the City of Tijuana, and other interested stakeholders informed to ensure that results be used in landuse decisions that will help protect the environment and human health.

ENVIRONMENTAL ISSUE

Excessive erosion in Tijuana during storms produces sediment loads that bury native vegetation, lock tidal channels, and enter coastal zones to impact wildlife adversely. Erosion also threatens human life by causing roads and houses in Mexico to collapse and the Tijuana River Valley in the U.S. to flood.

RESEARCH GOAL

The main goal of the project is to find ways to control soil erosion and sediment loss of the Tijuana River watershed effectively. This project also demonstrates the impacts of future land cover change including road paving and continued urbanization, and mitigation strategies such as low impact development and retention basins on watershed hydrology and sediment loss.

METHODS AND PROCEDURES

The Study Area

Study area

Flow carries sediment, tires and trash

After Rainfall

Sediment buries vegetation

Sediment removal

CONCEPTS Model

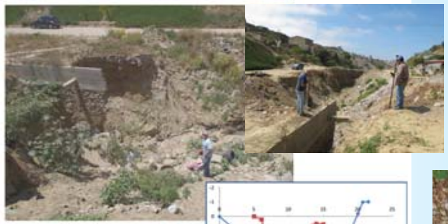
The CONservational Channel Evolution and Pollutant Transport System (CONCEPTS) simulates unsteady flow, transport of cohesive and cohesionless sediments selectively by size class, and bank erosion processes in stream corridors (Langendoen and Alonso 2008; Langendoen and Simon 2008). Hence, it can predict the dynamic response of flow, sediment transport, and channel cross-sectional geometry to disturbances including channelization, altered hydrologic regime (e.g., by dam construction or urbanization), or in-stream hydraulic structures. This section summarizes: (1) the characterization of these processes in CONCEPTS; and (2) input data required by the model.

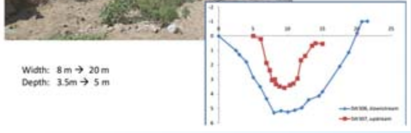
CONCEPTS assumes stream flow to be one dimensional along the centerline of the channel. It computes the flow as a function of time simultaneously at a series of cross sections along the stream using the Saint Venant equations (Cunge et al. 1980). The governing equations are discretized using the generalized Preissmann scheme, and the resulting set of algebraic equations is solved using Gaussian elimination with partial pivoting for banded matrices (Langendoen and Alonso 2008). Required input data are: channel form, channel boundary roughness, and water inflows.

CONCEPTS calculates total-load sediment transport rates by size fraction from a mass conservation law and taking into account the differing processes governing entrainment and deposition of cohesive and cohesionless bed material (Langendoen and Alonso 2008). Following Hirano (1971), CONCEPTS divides the bed into a surface or active layer and a subsurface layer. Sediment particles are continuously exchanged between the flow and surficial layer, whereas particles are only exchanged between the surface layer and substrate when the bed scours and fills. For cohesive materials, the erosion rate is calculated by an excess shear stress approach. For cohesionless materials, CONCEPTS assumes that the erosion or deposition rate is proportional to the difference between the sediment transport rate and sediment transport capacity (Bennett 1974). Sediment transport capacity is calculated by a modified version of the sediment transport capacity predictor SEDTRA developed by Garbrecht et al. (1995). Total sediment transport is calculated by size fraction for 14 predefined size classes, with a suitable transport equation for each class: as wash load without deposition for sizes smaller than 10 um; Laursen (1958) for silts; Yang (1973) for sands; and Meyer-Peter and Müller (1948) for gravels. Required input data are: grain size distribution and stratigraphy of the bed material, critical shear stress and erodibility of cohesionless bed material, and sediment inflows.

Channel Stability Ranking

Channel stability has been assessed at 21 locations in Los Laureles Canyon. The selection of the locations for measurement is where significant changes occurred in channel cross section, changes in indicators of erosion, and hardpoints like road crossings.



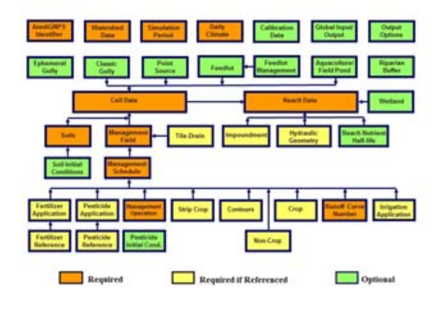


Impacts of Hardpoints

AnnAGNPS Model

The Annualized AGricultural Non-Point Source (AnnAGNPS) pollutant loading model is an advanced simulation model developed by the USDA-Agricultural Research Service and NRCS to help evaluate watershed response to agricultural management practices (Bingner et al., 2009). It is a continuous simulation, daily time step, pollutant loading model designed to simulate water, sediment and chemical movement from agricultural watersheds (Bingner et al., 2009). The AnnAGNPS model evolved from the original single event AGNPS model (Young et al., 1989), but includes significantly more advanced features than AGNPS. The spatial variability of soils, land use, and topography within a watershed can be determined by discretizing the watershed into many user-defined, homogeneous, drainage-area-determined cells. From individual cells, runoff, sediment and associated chemicals can be predicted from precipitation events that include rainfall, snowmelt and irrigation. AnnAGNPS simulates runoff, sheet and rill, and ephemeral gully eroded sediment and chemicals leaving the land surface and the transport of each pollutant load through the channel system to the watershed outlet on a daily time step. Since the model routes the physical and chemical constituents associated with each pollutant source from each AnnAGNPS cell into the stream network and finally to the watershed outlet, the model has the capability to identify pollutant sources at their origin and to track those pollutants as they move through the watershed system. The complete AnnAGNPS model suite, including programs, pre- and post-processors, technical documentation and user manuals, is currently available at http://www.ars.usda.gov/Research/docs.htm?docid=5199.

AnnAGNPS Input Data Section



Rainfall, Runoff and Sediment Monitoring

Rain gauge set up

Three pressure transducers are installed at different locations to measure flow and suspended sediment.

Monitored rainfall, runoff and sediment are used for AnnAGNPS model calibration and validation

Bed and Bank Material Characterization

If bed material consists of coarse particles (particles 2 mm or greater in diameter), a particle count is carried out

Bed Characterization

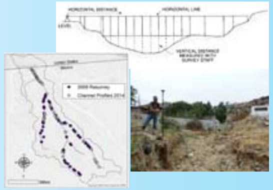
Bank Characterization

The intermediate axis of one hundred particles is measured, not the largest, nor the smallest length, in millimeters using a ruler or tape measure in the field (metric units to a tenth of a centimeter accuracy). These will be measured across the channel in order to represent a range of different particle sizes found across the bed.

Measurements of Gully Dimensions

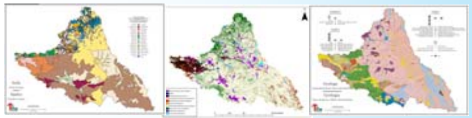
Gully presence/absence was noted visually on unpaved roads and dimensions was measured in the field within 2 days of storm events, since road maintenance often fills in gullies rapidly after storms. Gully presence was surveyed visually along the two main roads of the canyon starting at the southern end of the canyon. A total of 10 gullies was surveyed after each storm with a tape measure and survey rod. GPS points were taken with a survey-grade GPS at the beginning and end of the gully, and at all locations where width and depth are measured. Repeat surveys of the same gully were taken for the 3 largest gullies; the other 7 were new sites. Surveys begin at the gully head, and a GPS point taken at the head with a survey-grade GPS. Width and the depth at each bank and the maximum depth are measured every 10 m until the gully terminates, and a GPS point collected at each width and depth measurement. The slope between sampling sites is determined with an auto level or from the 5-m DEM. The longitudinal profile survey of a few gullies of various sizes was performed to compare to the information determined from the 5-m DEM. The location of each width-depth measurement is taken with a GPS and a photograph taken with the sample date and site number recorded in the frame with a white board.

Channel Geometric Survey



Channel Profiles: 1) 38 Locations resurveyed from 2008; 2) 79 Additional locations surveyed in 2014

Model Setup and Simulations



Soil map of the Tijuana River watershed. Landuse/landcover of the watershed Geology of the Tijuana River watershed

Pilot study area: the left figure shows AnnAGNPS subwatersheds for Goat canyon; the right figure shows CONCEPTS channels for Goat canyon.

Based on the Digital Elevation Model (DEM), the watershed and associated subwatershed boundaries were delineated. Geographical Information System (GIS) soil and land use maps were used in conjunction with the subwatershed map to determine the predominant soil and land use to assign to each subwatershed. The topographic, soil, and land use information were imported through the AnnAGNPS Input Editor to produce the necessary AnnAGNPS input.

The AnnAGNPS is used to simulate streamflow, sheet and rill erosion as well as gully erosion. CONCEPTS is used to simulate channel processes including channel erosion and deposition. CONCEPTS takes outputs from AnnAGNPS, along with channel geometric information, channel stability information Manning's roughness, and bed and bank characterization to simulate channel processes to produce the total sediment loading the watershed.

PRELIMINARY RESULTS

Lessons Learned

- Severe gully formation occurs on specific geologies, particularly those with low cobble fractions.
- Channel sediment is continually replenished by both channel maintenance and dumping of material from construction and excavation.
- Validation of the model is complicated by lack of rainfall during the period of instrument deployment.
- 3D reconstructions of channels will allow for high-resolution change detection of channel erosion.

Continued efforts

- DJI Phantom 2 quadcopter and GoPro camera to map and quantify ephemeral gullies in dirt roads and create digital terrain models
- Estimate annual total sediment loading including all sources (landscape, gullies and channels) from the existing condition of the watershed and future scenarios such as following implementation of LIDs/green Infrastructure
- Work with stakeholders to halt unplanned development
- Evaluate the impact of LIDs on hydrology, flood risk, erosion and sediment loss.
- Implement suitable LID/Green Infrastructure to control sediment loss.

Local Efforts to Control Erosion

Low Impact Development

Acknowledgements