Remote Sensing Technology for Development Planning Along the US-Mexico Border: Hydrogeology and Geomorphology

Authors: A. Granados-Olivas and H.C. Monger
Date: Nov. 1, 1999
From: New Mexico Journal of Science
Publisher: New Mexico Academy of Science
Document Type: Article
Length: 2,833 words

Full Text:
H.C. Monger [17]

Abstract

Arid land ecosystems along the border region of the United States and Mexico are being rapidly developed. Two of the most important natural resources of this region are water and soil. Hydrogeological characteristics (such as the size and quality of aquifers) combined with geomorphic units (such as alluvial fans and floodplains), provide important information that can help prevent poorly planned development. Making these maps involves 1) delineating geomorphic features based on aerial photographs and satellite images, 2) ground-truthing the features, and 3) combining geomorphic maps with groundwater maps using GIS (Geographic Information System). These hydro-geomorphic maps help to locate high producing wells, as along faults, and identify groundwater recharge zones, as along mountain arroyos. Moreover, these hydro-geomorphic maps identify areas unsuitable for development. For example, housing development should not take place in arroyo and river floodplains, which are subject to flooding. Instead, housing sh ould occur on higher, geomorpho logically stable fan-piedmont surfaces. Building on stable surfaces not only will protect houses from flooding and erosion, but also will preserve the topographically lower and texturally finer floodplains for agriculture, wildlife, and recreation.

Introduction

Water and soils are among the most important natural resources for sustainable urban and rural development in desert ecosystems. To meet the challenging demands for these natural resources in the near future, a thorough understanding of soil science and hydrogeology is required. Many studies have been conducted on how arid ecosystems have been affected by development (Dregne 1976). It is well understood that as demographic pressures increase in these areas, pressure on soil and water resources will increase as well. Agricultural production in desert environments requires large quantities of water applied to soils where the crops are grown. The amount of water used depends on crop type, evapotranspiration, irrigation method (drip vs. flood), agricultural versus urban uses, and type of soils.

Urban growth exerts major pressure on these two resources. The immersion of productive soils and consumption of water resources by urban expansion is common in developing desert regions along the US-Mexican border. Demand for soil for housing and industry to sustain economic growth will increase and change land-use patterns. Demands for irrigation water also will increase. It has been estimated that from 1977 to 1990, worldwide irrigated areas increased by 50 million hectares (123 million acres), from 223 to 273 million hectares (from 550 to 674 million acres) (Cuenca 1989). Worldwide, this represented 13% of the total arable land and 34% of all crops produced (Cuenca 1989).

Although irrigation has allowed crop production in arid and semi-arid regions, most of these regions depend on groundwater resources. Since only intermittent surface water from torrential seasonal rains occur in these areas, only a small fraction of the current precipitation will recharge the groundwater reservoir. Moreover, the extreme temperatures and high evapotranspiration rates of desert environments limit water storage in soil. High evaporation also hinders the development of hydraulic infrastructures, such as water-capturing dams, that could supply irrigation districts. An exception is where perennial rivers and streams flow from higher elevations where precipitation is higher. Still, water from aquifers supplies approximately 40% of the total irrigation water in the United States (Soule et al. 1990). For example, in New Mexico alone there are 130,000 irrigation wells (fig. 1) (JOI 1999).

Drop of water table conditions on unconfined aquifers, and piezometric drop for confined aquifers, has accompanied large withdrawals of groundwater in the southwestern United States. In New Mexico, groundwater withdrawal and the lowering of water tables are common. For example, fig. 2 illustrates groundwater levels of Luna Gounty, New Mexico (Wilkins et al. 1995). The trend in groundwater levels for this region has been the result of water withdrawal for developing agricultural fields.

Soils and groundwater are components of desert ecosystems. Understanding relationships between water, soils, geology, and other ecosystem components is necessary for sustainable development in desert regions. Toward that goal, this paper identifies important geomorphic features in the border region of northwestern Chihuahua, Mexico, and their relationship to groundwater and development. The application of remote sensing and GIS can play an important roles in preventing unplanned development.

The Transboundary Border Region

The United States and Mexico share a common border extending 3090 km (1,920 miles) from the Gulf of Mexico to the Pacific Ocean. Eight major basins occur along this border region, of which four are shown in fig. 3. Region 4 has been denominated the Mimbres-Animas Basin on the US side and by the Bolson de los Muertos (Bolson of the Dead) on the Mexican side. The total extent of region 4 is about 32,246 [km.sup.2] (12,400 square miles) and is divided into 5 major sub-basins that drain internally in southern New Mexico and northern Chihuahua. The total area is divided almost in half, so the US side the region has 16,226 [km.sup.2] (6,240 square miles) and the Mexican side has 16,019 [km.sup.2] (6,160 square miles). One of the sub-basins, which this paper will be addressing, is the Lower Gasas Grandes Basin (Hawley 1998).

The Lower Casas Grandes Basin

The Lower Casas Grandes Basin (LCGB) is located in the Mexican Highlands section of the Basin and Range Province (fig. 4). The largest stream in the interior drainage system of the bolson region is the Rio Casas Grandes heading in the Babicora-Bustillos subsection, east of the Sierra Madre Occidental. The Casas Grandes River flows north into the Basin and Range Section of northwestern Chihuahua or Bolson Subsection. In this region, the mountains rise above almost flat lands and constructional plains, with broad bajadas and piedmont slopes, alluvial flats, and ephemeral lake-plains. The elevations in these basins and mountain chains ranges from 1190 to 2290 m above sea level (3,967 to 7,633 feet above sea level) (Hawley 1969).

During pluvial (wet) episodes in the early to middle Pleistocene, internally drained basins captured large amounts of water from at least four major river systems (Hawley 1993). One exceptionally large lake has been named Pluvial Lake Palomas (fig. 4) (Reeves 1969). The lake was filled by Rio Casas Grandes, Rio Carmen, Rio Santa Maria, and Rio Mimbres.

Climatic differences in the recent past could have been at least 12[degrees]C (22[degrees]F) lower and precipitation about 250 mm (9.8 inches) higher than present climatic conditions (Antevs 1954). The location of the study is between 31[degrees]57' to 31[degrees]40' of north latitude and 107[degrees]40' to 107[degrees]35' of west longitude (fig. 4). Presently, average annual precipitation is between 200 to 300 mm/yr (8 to 12 inches/year) and evapotranspiration rate is about 2400 mm/yr (95 inches/year). Extreme temperatures can range from 25[degrees] to 30[degrees]C (77[degrees] to 86[degrees]F) in summer to -2[degrees] to -10[degrees]C (28[degrees] to 14[degrees]F) in winter. The only available water resources for the Lower Casas Grandes Basin is groundwater, and the main economic activities of the region are crops and livestock. The population growth rate in the municipality of Ascension, Chihuahua in the Lower Gasas Grandes Basin, is about 7% per year (Tanski et al. 1998). Torrential storms and eolian pro cesses are the dominant geomorphic processes.

Geomorphic Features and Hydrogeologic Characteristics on the Lower Casas Grandes Basin

The major geomorphic features useful for the understanding natural resources necessary for sustainable development include stream locations, sands and gravel, slopes, the best-suited locations for agriculture, and sites with potential risk for flooding and slides. The identification of different landforms also helps in estimating the distribution, size, age, and type of soils; depth to bedrock; rock stratigraphy; and correlation of landscapes units (Peterson 1981). Three major physiographic parts and 8 main landforms are identified in the bolson subsection of the Lower Gasas Grandes Basin in (see table 1) (Morrison 1969; Peterson 1981).

The upper piedmont zone contains the bounding mountains (identified by "H"). This hilly region has less than 300 m (1,000 feet) of local relief and acts as water divides for the area (fig. 5). Bedrock is mainly Cretaceous limestone (145 million years old) with a high degree of weathering, which produced colluvial debris of the alluvial fans. Mountain bounding on the north side of the image are basaltic lava flows of probably mid-Pleistocene age ([less than] 800 thousand years old) (Morrison 1969). The alluvial fans (A) have a gentle slope ranging from [less than]10 to 25%. The extension of these alluvial fans terminates at the intersection with the flatter basin floor (F). Some of these alluvial fans are dissected by local faulting, which cuts the fan toeslopes (ending parts) (fig. 6). Ballenas (B) are eroded fan remnants. The arroyos between ballenas usually carry loads of gravel and rock, which allow runoff from torrential summer rains to infiltrate and recharge aquifers.

The linear ending of the toeslopes on the fan piedmont and pediments are commonly related to structural faulting (fig. 6). These linear features also are potential areas of recharge and greater groundwater flow because fractures provide flow routes to subsurface groundwater capturing environments. Fracture trace analysis is a technique that uses linear features to find high-yielding wells on sedimentary and karst terrains (Vincent 1997). In the study area, the structural faulting can be identified on both piedmont and basin floor zones. Computer processes as well as visual interpretation of satellite imagery and aerial photographs enhance the visual appearance of these linear features so they can be differentiated from anthropogenic linear features.

On the middle piedmont zone, the fan piedmonts (P, fig. 5) are major geomorphic features in the Basin and Range. Fan piedmonts are formed by the coalescence of semiconical, fanshaped alluvial piedmonts that slope down into the basin floors. In some of the older literature, the term bajada, which is Spanish for "down sloping," was used to identify these geomorphic features. Fan piedmonts have several morphogenetic features (such as fan remnants, inset fans, fanlettes, and fan collars) that comprise information related to their age, soil type, geographic distribution, parent materials, and morphogenetic configuration (Dorn 1994).

Another major geomorphic feature on the middle piedmont zone are the fan skirts (S). These are considered part of the fan piedmont, although they are transitional to the basin floor. Soils on fan skirts are younger products of weathering and deposition than soils on topographically higher fan piedmonts. Some of these have been dated as Holocene in age ([less than]10,000 years) (Morrison 1969). Fan skirts are commonly well-suited for agriculture if irrigation is available (Peterson 1981). However, as with many desert and semidesert environments, the salt accumulation from parent materials due to poor drainage may limit agricultural development. In some cases, weak soil structure and high sand content allows for wind erosion, also limiting the types of crops that can be grown. Some of these problems are being offset by drip irrigation and windbreak infrastructure. However, their high costs limit the use of these techniques.

The last physiographic zone is the basin floor. Three major geomorphic units dominate the smooth, nearly level basin floor. These are the alluvial flats (F), floodplains (FP), and playas (Y). The alluvial flat (F, fig. 5) extends from the ending part of the fan skirt (S), to the deepest part of the basin floor. This region of the basin floor usually is composed of either a floodplain (FP) (in the case of an entrenched basin floor) or a playa or internally drained lagoon (in the case of non-entrenched basin floors) (fig. 7).

Floodplains (FP) comprise modern drainage systems and are some of the most productive agricultural soils in desert environments. The low gradient and sometimes broad extensions of these floodplains rework and deposit fine-textured alluvial and fluvial sediments with high productivity. Nutrient-rich soils are common on these geomorphic features, as are well-sorted stratified sand and gravel and transported materials. Groundwater possibilities are good in floodplains where coarser materials occur as paleochannels (old or relict floodplains). Playas (Y) are the lowest parts of closed basins. Many playas were pluvial lakes and have lacustrine landforms (i.e. shorelines, barrier bars, and offshore bars). Playas are common sources of eolian sediments. Playa centers have fine-textured sediments (commonly clays), are usually barren of vegetation, and have shrinking-swelling properties. As a result, playas have special characteristics to consider for engineering purposes, and are sites of low-yielding irrigation well s.

Conclusions

Soils and water resources should play a major role in present and future development of arid and semi-arid regions of the world as population increases. Understanding morphogenetic characteristics, parent materials, topographic arrangement, and ages of geomorphic features will help us identify important types of soils and groundwater-capturing environments. This understanding will also identify flood-prone areas, such as arroyos and river floodplains, where construction should be avoided.

As satellite imagery keeps improving, the usefulness of this imagery will increase. Although mapping of many arid regions of the United States continues, many regions in the arid lands of Mexico are still unmapped. Therefore, attempts to increase mapping data are necessary to fill in the gap for the border region. The mapping and identification of geomorphic features based on remote sensing (satellite or airborne) is a useful technique for land-use planning. Field checking of the mapped geomorphic features remains an important process.

A thorough understanding of geomorphic features and their relationship to groundwater and soil resources is required for the transboundary border region between the United States and Mexico, where rapid demographic pressures and economic development is currently taking place.

(17.) Engineer, Professor at the Environmental Studies Center, Institute of Engineering and Technology, Autonomous University of Ciudad Juarez and Ph.D. Candidate at NMSU (algranad@nmsu.edu); and Associate Professor, Department of Agronomy and Horticulture, New Mexico State University, Las Cruces, 88003

References

Anteves E. 1954. Climate of New Mexico during the last Glacio-Pluvial. Journal of Geology. 62:182-191.

Cuenca R.H. 1989. Irrigation system design: An engineering approach. Upper Saddle River (NJ): Prentice Hall.

Dregne H.E. 1976. Soils of arid regions. Amsterdam: Elsevier Scientific.

Dorn R.I. 1994. The role of climatic change in alluvial fan development. IN: Abrahams A.D., Parson A.J., editors. Geomorphology of desert environments. London: Chapman and Hall. p 593-615.

Hawley J.W. 1969. Notes on the geomorphology and late Cenozoic geology of northwestern Chihuahua. IN: Cordova D.A., Wengerd SA., Shoemaker J., editors. The border region, Chihuahua, and the United States; New Mexico Geological Society 20th field conference. Socorro (NM): New Mexico Geological Society.

Hawley J.W. 1981. Geology and geomorphology, section 2. IN: Gile L.H., Hawley J.W., Grossman R.B. Soils and geomorphology in a basin and range area of southern New Mexico, guidebook to the Desert Project. Socorro (NM): New Mexico Bureau of Mines and Mineral Resources. (Memoir 39.) p 22-51.

Hawley J.W. 1993. Geomorphic setting and late Quaternary history of pluvial-lake basins in the southern New Mexico region [open-file report 391]. Paper presented at the conference on the paleoecology of Pendejo Cave and its environs; 1992 April 3-6; Orogrande Base Camp, Fort Bliss, Orogrande, NM. Socorro: New Mexico Bureau of Mines and Mineral Resources.

[INEGI] Instituto Nacional de Estadistica Geografia y Informatica. 1996. SINFA Esc. 1:75000; 23 de Mayo de 1996; Zona H13-1 Linea 86.

[JOI] Journal of Irrigation. 1999 Jan-Feb. 1998 annual irrigation survey. Journal of Irrigation 49(1).

Morrison, R.B. 1969. Photointerpretive mapping from space photographs of Quaternary geomorphic features and soil associations in northern Chihuahua and adjoining New Mexico and Texas. IN: Cordova D.A., Wengerd S.A., Shoemaker J., editors. The border region, Chihuahua, and the United States; New Mexico Geological Society 20th field conference. Socorro (NM): New Mexico Geological Society. p 116-129.

Peterson F.F. 1981. Landforms of the Basin and Range Province, define for soil. survey. Reno: University of Nevada Reno, Nevada Agricultural Experiment Station. (Technical bulletin 28.)

Reeves C.C. Jr. 1969. Pluvial Lake Palomas, northwestern Chihuahua, Mexico. IN: Cordova D.A., Wengerd S.A., Shoemaker J., editors. The border region, Chihuahua, and the United States; New Mexico Geological Society 20th field conference. Socorro (NM): New Mexico Geological Society. p 143-154.

Schmidt R.H. Jr. 1986. Chihuahuan climate. IN: Campos E., Anderson R.J., editors. Chihuahuan Desert-US and Mexico, part 2. El Paso: University of Texas at El Paso, Department of Geological Sciences. p 40-63.

-----. 1989. The arid zones of Mexico: Climatic extremes and conceptualization of the Sonoran Desert. Journal of Arid Environments 16:241-256.

Soule J., Carre D., Jackson W. 1990. Ecological impact of modern agriculture. IN: Carroll C.R., Vandermeer J.H., Rosset P., editors. Agroecology. New York: McGraw-Hill. (Biological resource management series.) p 165-188.

Tanski J., Hanson A., Granados A., Samani Z. 1998 (in press). Water quality assessment plan for Columbus, NM, and Puerto Palomas, Chih. (SCERP project FY-1997.) Southwest Center for Environmental Research and Policy.

[USGS] United States Geological Survey. 1996 Feb. United States-Mexico border area, as delineated by a shared-water resources perspective. Reston(VA): USGS.

Vincent R.K. 1997. Remote sensing applications to petroleum and ground water exploration. IN: Fundamentals of geological and environmental remote sensing. Upper Saddle River (NJ): Prentice Hall. (Geographic Information Science; Clarke K.C., series editor.) p 214-256.

Wild A. 1993. Soils and the environment: An introduction. Cambridge (UK): Cambridge (UK): Cambridge University Press.

Wilkins D.W., Garcia B.M. 1995. Ground-water hydrographs and 5-year ground-water-level changes, 1984-1993, for selected areas in and adjacent to New Mexico. Albuquerque (NM): US Geological Survey and New Mexico State Engineer Office. (USGS open file report 95-434.)