WATER OPERATION AND MAINTENANCE BULLETIN

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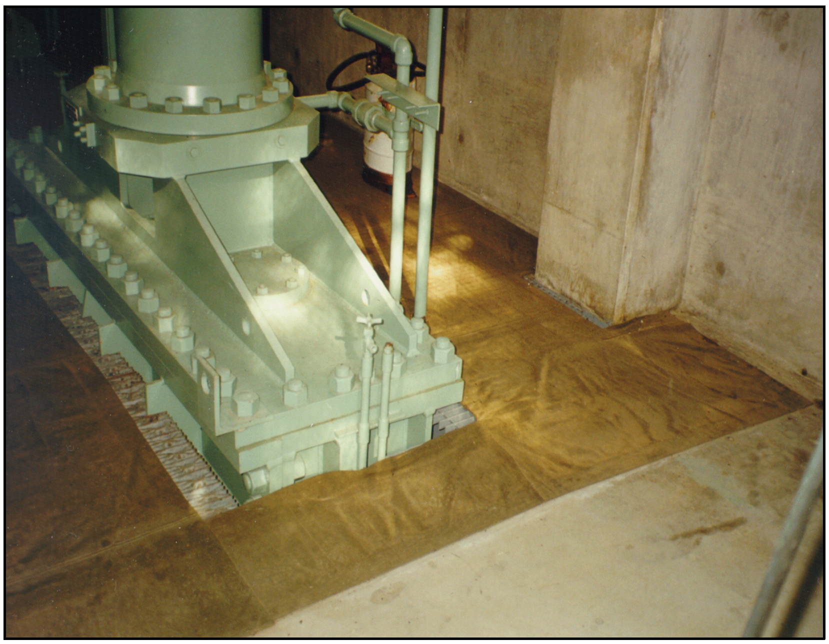

IN THIS ISSUE. . .

UNITED STATES DEPARTMENT OF THE INTERIOR **Bureau of Reclamation**

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This *Water Operation and Maintenance Bulletin* is published quarterly for the benefit of water supply system operators. Its principal purpose is to serve as a medium to exchange information for use by Reclamation personnel and water user groups in operating and maintaining project facilities.

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***Cover photograph*:** Canvas tarpaulin around jet-flow gate hoist in the outlet works control house at Boca Dam.

UNITED STATES DEPARTMENT OF THE INTERIOR Bureau of Reclamation

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CONTENTS

Page

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ADVANCES IN THE POSITIONAL ACCURACY OF IMAPS COMPUTERIZED FLOOD MAPPING GIS DATABASES

by Ronald Miller, Douglas Clark, and Kurt Wille

Background

In 1996, the Bureau of Reclamation's (Reclamation) Remote Sensing and Geographic Information Group (RSGIG) embarked on a new program to automate Reclamation's dam breach flood mapping capability using geographic information system (GIS) technology. More than 60 digital data themes were processed and compiled into a user-friendly ArcView/Avenue GIS application that allowed them to be queried, displayed, and analyzed. The purpose of this application was to analyze the human populations and structures that might be affected by the floodwaters of a dam breach or operational release. The resulting GIS database analysis capability became part of what is now IMAPS (Inundation MApping ProductS).

These data themes were extracted from secondary data sources, such as census block Topologically Integrated Geographic Encoding and Referencing (TIGER) files, the Federal Emergency Management Agency Standard Industrial Classification Code database, the American Hospital Association hospital database, U.S. Department of Transportation bridge database, the Geographic Name Information System from the U.S. Geological Survey (USGS), the hazardous waste facilities files from the Environmental Protection Agency, the National Inventory of Dams database, U.S. Department of Agriculture and Census Bureau's Census of Agriculture, among others.

In the course of compiling these data themes, RSGIG began to encounter a variety of positional accuracy problems. These included accurately locating facilities within census polygon units such as blocks, block groups, and counties; displacements owing to incorrect addressing or hierarchical addressing procedures; source data inaccuracies; and the relations of scale to map symbology.

Issues Surrounding Base Data

Table 1.1 lists most of the facilities that Reclamation is currently mapping for the purposes of dam breach analysis as well as the related locational accuracy issues (see previous paragraph) associated with them. Linear features such as hydrography, roads, utility lines, and railroads have been left out because they have not presented the same magnitude of positional accuracy issues that point and polygon data have presented. What follows is a description and analysis of the various locational problems we have faced in our dam breach mapping and impact analysis efforts.

Table 1.1 Positional Problem Profiles

Data Theme	Type	Position In Polygon	Addressing Problems	Original Location Methods	Symbology/Scale	Scale Differences
Agricultural Services	point	☐	☑	☐	☐	☐
Airport Services	point	☐	☑	☐	☐	☐
Airports	point	☑	☐	☑	☑	☐
Amusement Parks	point	☐	☑	☐	☑	☐
Block Group Housing	poly	☑	☐	☐	☐	☑
Bridges (Major)	point	☐	☐	☑	☐	☐
Camps and Parks (Private or Commercial)	point	☐	☑	☐	☑	☐
Camps and Parks (Public)	point	☐	☐	☑	☑	☐
Census Block Resident Population Estimates	poly	☑	☐	☐	☐	☑
Communication Services	point	☐	☑	☐	☐	☐
Communication Towers	point	☐	☐	☑	☐	☐
Correctional Facilities	point	☐	☑	☐	☐	☐
Dams	point	☐	☐	☑	☐	☐
Electric Power Plants	point	☐	☑	☑	☐	☐
Farming (County Level USDA/Census Data)	poly	☑	☐	☐	☐	☑
Farms (Commercial)	point	☐	☐	☐	☑	☐
Fire Protection	point	☐	☑	☐	☐	☐
Fisheries	point	☐	☑	☐	☐	☐
Food Providers	point	☐	☑	☐	☐	☐

Page 1 of 3

Data Theme	Type	Position In Polygon	Addressing Problems	Original Location Methods	Symbology/Scale	Scale Differences
Forest Services	point	☐	☑	☐	☐	☐
Gas Plant	point	☐	☑	☑	☐	☐
Gas Storage Site	point	☐	☑	☑	☐	☐
Government Facilities	point	☐	☑	☐	☐	☐
Hazardous Materials Sites and Facilities	point	☐	☑	☑	☐	☐
Health Facilities	point	☐	☑	☐	☐	☐
Hospitals	point	☐	☑	☐	☑	☐
Hunting and Fishing/Sportsman Services	point	☐	☑	☐	☐	☐
Industries	point	☐	☑	☐	☐	☐
Irrigation Systems Services	point	☐	☑	☐	☐	☐
Livestock	point	☐	☑	☐	☑	☐
Lodging Services	point	☐	☑	☐	☐	☐
Military Installations	point	☐	☑	☐	☑	☐
Mining	point	☐	☑	☐	☑	☐
Museums	point	☐	☑	☐	☐	☐
Nuclear Power Plants	point	☐	☐	☐	☑	☐
Petro-chemical Plants	point	☐	☑	☐	☑	☐
Police	point	☐	☑	☐	☐	☐
Public Water Supply Plant	point	☐	☐	☑	☐	☐
Rail Yards	point	☐	☑	☐	☐	☐
Railroad Services	point	☐	☑	☐	☐	☐

Data Theme	*Type*	*Position In Polygon*	*Addressing Problems*	*Original Location Methods*	*Symbology/Scale*	*Scale Differences*
Recreational Facilities	point	☐	☑	☐	☐	☐
Refineries	point	☐	☑	☐	☐	☐
Schools (FEMA)	point	☐	☑	☐	☑	☐
Schools (GNIS2)	point	☐	☐	☑	☑	☐
Sewer Plant	point	☐	☐	☑	☐	☐
Tank Farm	point	☐	☐	☑	☑	☐
Utility Services	point	☐	☑	☐	☐	☐

Locating Facilities Within Census Geographic Polygon Units

The first category of error deals with the location of residences and various other facilities within standard census polygon units such as blocks, block groups, and counties. Census TIGER line files do not indicate where human populations and infrastructure are located within their block, block group, tract, county, or other geographic boundaries. Residences or facilities might be clustered in a single corner, spread evenly throughout, or randomly scattered. This fact became problematic when a particular block was only partially inundated. The user of these data might ask, "Where are the population and structures within this census block in relation to the flood boundary?" In the absence of recent aerial photography, money to conduct field work, or detailed maps, we were forced to make the assumption that populations and facilities were evenly distributed within each polygon.

Street Addressing Technology

The second category of positional inaccuracy arose from limitations in street addressing technology and base data. In some cases, the street system graphic files lacked sufficient currency to adequately locate addresses on recently constructed streets. In others, the base address data were either inaccurate (i.e., mis-spelled, out of range, abbreviated, etc.) or simply lacked a relevant geographic location. Addresses that were listed as post office boxes, for instance, fell into this latter category. Finally, some of our data providers used an hierarchical scheme to locate addresses. If the exact address could not be found, then the establishment was placed successively on a census block face, block centroid, zip code plus four digits centroid, zip code plus two digit centroid, and, finally, a zip code centroid. In rural areas, particularly, we found that numerous addresses were being placed a substantial distance away from the city listed in the address.

Original Data Compilation: Scale Differences

A third category of inaccuracy appeared from point location procedures originating from the source of the data. Sometimes, for instance, latitude and longitude point locations were taken from, or appeared to be taken from, small-scale maps of the entire United States but then were reported as accurate to the nearest second, a distance ranging from about 80 to 200 feet. This sometimes resulted in substantial error. In other cases, no location was given at all. This was especially true of bridge data. In still others, data were measured correctly but then miscoded in the database. It was not uncommon, for instance, to find a dam in the wrong county because the minutes and seconds had been reversed.

Map Symbology and Scale

Finally, data inaccuracies arose from the symbology used to represent features on the surface of the earth. For instance, a park reported as a point in space could easily be physically present both inside and outside of a flood inundation zone. The same could be true of any number of other facilities. For instance, a hospital may be a point on a city map but an area polygon on a map of the immediate local vicinity. As all geographers know, what can be represented as a point on a small-scale map (e.g., a State park on a map of the United States) becomes a polygon on a larger-scale map (i.e., a county map).

Summary

In the course of working with the various data themes, RSGIS found that positional inaccuracies existed for data from virtually every source, both government and private. In the absence of better base data, or funds to gather our own, we needed to develop a set of procedures to improve the accuracy of that data we had available to us. With research funds recently provided to us from Reclamation's Dam Safety Office, we found six correctives to our positional accuracy problems. These included a better street addressing system (ArcView StreetMap 2000) with a more current street database; USGS digital orthophoto quadrangles; digital raster graphic quadrangles (DRGs); National Aerial Photography Program (NAPP) photos, and Internet resources. In addition, remotely sensed imagery has been identified which can add new land use data themes to the existing database. Image processing technology can be used to detect and classify land/land cover. These classified results can offer better ground area representation for existing themes as well as others that have not been available to date. Some of these themes can be produced by image processing of traditional multispectral satellite imagery, while more detailed information may be extracted from the new high-resolution commercial satellites just now being deployed. The use of aerial photography and satellite imagery represents a shift in our mapping work toward the use of some primary data as well.

Positional Rectification Procedures

Table 1.2 summarizes the techniques and supplementary data RSGIS can bring to bear to ameliorate locational inaccuracy issues and what techniques are appropriate for what particular data themes. These new techniques and associated data include geocoding with ArcView StreetMap 2000, photointerpretation of digital orthorectified quarter quads and/or aerial photography, remote sensing, and image processing and map interpretation using digital raster graphics. Internet resources have also been used to improve the locational accuracy of nearly all the data themes; since their usage is universal, they have not been listed as a field in table 1.2. The following is a discussion of these rectification techniques and/or associated data. Future data improvement initiatives using Thematic Mapper, IKONOS, and other satellite data are also discussed.

Table 1.2: Methods for Enhancing Locational Accuracy

Data Theme	*Type*	*DOQQ (Photointerp)*	*Aerial (Photointerp)*	*DRGs (Map Interp)*	*Geocoding*	*TM Imagery*	*IKONOS Imagery*
Agricultural Services	point	☑	☑	☑	☑	☑	☑
Airport Services	point	☑	☑	☑	☑	☐	☐
Airports	point	☑	☑	☑	☑	☑	☑
Amusement Parks	point	☑	☑	☑	☑	☐	☐
Block Group Housing	poly	☑	☑	☑	☐	☐	☑
Bridges (Major)	point	☑	☑	☑	☐	☐	☑
Camps and Parks (Private or Commercia	point	☑	☑	☑	☑	☑	☑
Camps and Parks (Public)	point	☑	☑	☑	☐	☑	☑
Census Block Resident Population Estim	poly	☑	☑	☑	☐	☐	☐
Communication Services	point	☐	☐	☐	☑	☐	☐
Communication Towers	point	☑	☑	☑	☐	☐	☐
Correctional Facilities	point	☑	☑	☑	☑	☐	☐
Dams	point	☑	☑	☑	☐	☐	☑
Electric Power Plants	point	☑	☑	☑	☑	☐	☐
Farming (County Level USDA/Census Da	poly	☑	☑	☐	☐	☑	☑
Farms (Commercial)	point	☑	☑	☑	☑	☑	☑
Fire Protection	point	☐	☐	☐	☑	☐	☐
Fisheries	point	☑	☑	☑	☑	☑	☐
Food Providers	point	☐	☐	☐	☑	☐	☐

Page 1 of 3

Data Theme	*Type*	*DOQQ (Photointerp)*	*Aerial (Photointerp)*	*DRGs (Map Interp)*	*Geocoding*	*TM Imagery*	*IKONOS Imagery*
Forest Services	point	☐	☐	☐	☑	☐	☐
Gas Plant	point	☑	☑	☑	☑	☐	☐
Gas Storage Site	point	☑	☑	☑	☑	☐	☐
Government Facilities	point	☑	☑	☑	☑	☐	☐
Hazardous Materials Sites and Facilities	point	☑	☑	☑	☑	☑	☑
Health Facilities	point	☑	☑	☑	☑	☐	☐
Hospitals	point	☑	☑	☑	☑	☐	☐
Hunting and Fishing/Sportsman Services	point	☑	☑	☑	☑	☐	☐
Industries	point	☑	☑	☑	☑	☐	☐
Irrigation Systems Services	point	☐	☐	☐	☑	☐	☑
Livestock	point	☑	☑	☑	☑	☑	☑
Lodging Services	point	☐	☐	☐	☑	☐	☐
Military Installations	point	☑	☑	☑	☑	☑	☑
Mining	point	☑	☑	☑	☑	☑	☑
Museums	point	☐	☐	☐	☑	☐	☐
Nuclear Power Plants	point	☑	☑	☑	☑	☑	☑
Petro-chemical Plants	point	☑	☑	☑	☑	☐	☐
Police	point	☐	☐	☐	☑	☐	☐
Public Water Supply Plant	point	☑	☑	☑	☑	☑	☐
Rail Yards	point	☑	☑	☑	☑	☐	☐
Railroad Services	point	☑	☑	☑	☑	☐	☐

Page 2 of 3

Data Theme	Type	DOQQ (Photointerp)	Aerial (Photointerp)	DRGs (Map Interp)	Geocoding	TM Imagery	IKONOS Imagery
Recreational Facilities	point	☑	☑	☑	☑	☐	☐
Refineries	point	☑	☑	☑	☑	☐	☐
Schools (FEMA)	point	☑	☑	☑	☑	☐	☐
Schools (GNIS2)	point	☑	☑	☑	☐	☐	☐
Sewer Plant	point	☑	☑	☑	☑	☐	☐
Tank Farm	point	☑	☑	☑	☐	☐	☐
Utility Services	point	☑	☑	☑	☑	☐	☐

ArcView StreetMap 2000

Of the 44 point data themes of business and other establishments we make use of for our flood mapping, 31 are supplied with street addresses as well as latitude and longitude coordinates. In the past, we have made use of latitude and longitude coordinates to assign locations on the earth's surface. However, as noted earlier, when hierarchical addressing procedures had been used to assign these coordinates to the input data, the result was often that many were placed in a zip code centroid location outside of town. This was especially true in rural areas. At a cost of $9,200, Reclamation obtained ArcView StreetMap 2000. This software package contains both an automated and interactive addressing system and a 1997 street database.

First, the software automatically locates what addresses it can in batch mode and then allows the user to interactively locate what addresses he or she can. Sometimes, for instance, a street address will contain a misspelling, a missing extension, or on abbreviation that prevents it from being assigned a location. ArcView StreetMap 2000 reports these addresses, tries to diagnose the problem in finding a location, and then offers possible appropriate locations, which the user can accept or decline. Using this package, we saw a 40-percent reduction in locational inaccuracies for address points. Prior to use of this software, inaccuracies ranged from 10 to 20 percent. With this software, the inaccuracies now range from 6 to 12 percent.

Most remaining inaccuracies result from two causes. Post office box addresses still cannot be assigned appropriate locations, and addresses on streets built after 1997 cannot be located using this software. Though, as will be seen, Internet resources can sometimes help ameliorate this problem. As before, RSGIS will continue to provide a list of addresses that could not be located in all dam breach projects for which they use ArcView StreetMap 2000. Making use of this technology will add 2-3 days labor to the average cost of an IMAPS project.

USGS Digital Orthophoto Quadrangles

A digital orthophoto quadrangle is a primary data source that may be regarded as a photographic map. A conventional aerial photograph contains image displacements and scale inconsistencies caused by camera lens distortion, camera tilt and tip, and terrain relief. The computerized rectification process used to create a digital orthophoto eliminates these. This USGS product offers data more current than that agency's 7.5-minute quad sheets that can be as much as 50 years old as they are produced from NAPP photography. Most digital orthophoto quadrangles (DOQs) Reclamation has used are less than 5 years old. In addition, they offer a ground resolution of 1 meter.

Photointerpretation is typically performed on DOQs or photos to extract required information. An analyst uses seven visual cues to classify content of photos. The visual cues are shape, size, tone, color, shadow, topographic location, and texture. Interpretation keys are developed for each specific application. These keys are sets of guidelines that allow interpreters to quickly identify features. They are categorized as selective and elimination keys. Selective keys contain examples and descriptions of target objects in a category and are grouped for comparative theme assignment. Interpreters use these keys to assign an object to the most likely target class. Elimination keys provide the interpreter with a process that starts with general information and works toward specifics to eliminate a ground object from all categories until only one remains. Elimination keys are more difficult to construct and require detailed organization.

Adding a rectified photographic base background to our analysis of flood impacts has helped to remedy location problems in several ways. Most importantly, we can now interactively estimate the proportion of residences inundated within each *partially flooded* census polygon. Problems within these polygons have occurred in the past. Obviously, in a *wholly flooded* polygon, *all* residences will be at risk, and there is no need to know where residences are located within the polygon. Reclamation has developed automated procedures to facilitate this interactive assessment of partially inundated polygons using ArcView Avenue scripting language. However, each polygon must still be visually inspected by the analyst. This, of course, adds some labor cost to each project.

Some problems remain. For instance, it is sometimes difficult to distinguish between an office or commercial complex and multiple family housing. In rural or frontier areas, housing is sometimes obscured by vegetation canopy. Finally, there is often a time disparity between the date of the photography and date of the decennial census. Housing may have been added, removed, or abandoned, resulting in the gain or loss of population.

DOQs help rectify problems associated with addressing, original location, original symbology, and scale differences as well *as in cases where a facility can be identified on the photography.* For instance, highway bridges across a river, powerplants, or tank farms are generally readily recognizable on DOQs, and displaced facility point symbols can be moved interactively. Partially inundated large facilities, such as university campuses, symbolized as points, can be placed inside the inundation zone. Again, these procedures can add labor costs to a project. However, the acquisition costs of the DOQs is minimal—$7 per quarter quad and a $300-$500 base fee. Color photography is becoming available at $15 per file.

RSGIG feels that using census block data alone within a partially inundated block is not sufficient. This is especially true in situations where the flood boundary is relatively narrow within large census blocks. RSGIG strongly suggests using DOQS's or recent aerial photography sources for these areas to estimate residential structures. This will result in somewhat higher costs but should be well worth it because it should significantly improve population statistics. Limitations associated with DOQS's include lack of full coverage for the 17 Western States, illumination variations between different dates, image contrast, and graininess of imagery due to scanning the photography.

National Aerial Photography Program Photos

It is the intent of the National Aerial Photography Program, coordinated by the USGS, to acquire 1:40000 scale photography across the United States every 5 years. That has varied somewhat because of budgetary constraints. Nevertheless, the program does provide nearly complete coverage of the entire United States on a fairly regular basis. Some areas, especially those in mountainous regions, have only spotty coverage. Each photograph is centered on a quarter quadrangle. Depending on Federal or State requirements, black and white or color infrared photography is available.

The chief advantage of using NAPP photography as a primary source of data is the ability to view facilities and terrain in three dimensions using a stereoscope or computerized 3-D viewing technology. Three-dimensional viewing allows users to see *structure*, which can help to identify facility type. For instance, balconies or surrounding facilities are key in helping to identify multifamily structures. These are much more visible in 3-D than in 2-D. In addition, placement on a slope is often an aid in identifying facilities such as radio towers. Preliminary tests have shown that hard copy stereo viewers have limited utility for displaying the detail desired. Another disadvantage of manual hard copy stereo viewing is that ancillary digital data are harder to associate with the photos.

Soft copy (computer screen) displays have shown potential. In the near future, RSGIG will be evaluating a product called Stereo Analyst. The will be a software plug-in that allows 3-D viewing of imagery, theme creation, and editing in a stereo environment. The software will work with either ArcView GIS or ERDAS image processing software. Currently, this software is in the beta testing phase but will be available in May 2000. Soft copy viewing has an advantage, as digital data such as census blocks or land use themes are easily overlaid in the viewer for reference.

USGS Digital Raster Graphics

Digital Raster Graphics are scanned digital reproductions of USGS topographic mapping products. Though they are frequently not current, sometimes as much as 50 years old, they still can provide invaluable information to those seeking to interpret and analyze flood effects. For instance, they will often show buildings obscured by vegetation on photography. Furthermore, these buildings are often labeled by type (e.g., school, hospital) and even name (e.g., South High School, Veterans Affairs Medical Center). As such, they can help relocate misplaced facilities such as dams. They can also help correct the symbology/scale problem by showing the actual boundaries of a facility. This is something aerial photography will not do. Public parks, hospitals, military installations, and so on have boundaries that may not be identifiable on photography.

DRGs are valuable aids in the photointerpretive process. However, owing primarily to the age of the data they represent, they must be used with caution. A former air force base may now be a housing development. Vacant open spaces might now be busy shopping malls, and the State park boundary may have doubled in size with the inflow of lottery funds. DRG acquisition costs are very nominal. There is a $45 base rate, and individual quad sheets are only $1 each. Some DRGs are free and available on the Internet.

Internet Resources

The Internet has placed enormous informational resources at the fingertips of any user. We use it in a variety of ways to locate facilities. First of all, some interactive map databases are even more current than those of ArcView StreetMap 2000. Streets and addresses not on StreetMap 2000 can sometimes be found using Internet mapping systems. The problem is that these databases must be queried one address at a time and are therefore very time consuming to use. For facilities that lack street addresses, the Internet offers local telephone yellow pages. These addresses can be obtained and then mapped using ArcView StreetMap 2000.

New Themes from Remote Sensing and Image Processing

Remote sensing is the science of obtaining primary information on a geographical area of interest through imagery acquired remotely without physically touching the site. RSGIG has received requests about land use impact statistics from modeled flood scenarios. Existing GIS data themes have been hard to come by to meet these requests in the past. RSGIG has performed studies to produce such statistics using remote sensing and image processing technology. Image acquisition sources for these applications may be derived from airborne sources but most commonly are acquired by satellite platforms. Image data range from relatively high resolution, black and white, single-band panchromatic data to multiband, and multispectral color imagery. Multispectral color imagery may contain a combination of visible and infrared image bands. These image sources are extremely useful for vegetation, land use, and water body delineation and analysis.

Example projects include irrigated land inventories for consumptive use, riparian/wetlands vegetation inventories, land suitability, land use trend analysis, groundwater salvation infrastructure, and a wide variety of water body analysis. Images can be produced by analyzing different parts of the electromagnetic spectrum and organized and structured in image segments called bands. Typical ground resolutions for panchromatic imagery are 5 to 15 meters. Multispectral imagery is produced at 20-30 meters from traditional sources. Remote sensing, photointerpretation and image processing of these various image sources can aid in delineating infrastructure and land use/land cover.

Depending on the type of imagery acquired and target to be identified, image processing techniques will differ. Multispectral imagery is processed by transforming the original image bands into new bands of imagery that are noncorrelated and optimized for specific applications. Examples of this would include the tasseled cap transformation for agriculture and principal components analysis for infrastructure. Thematic classifications are then performed using supervised or unsupervised processing. A supervised classification is performed if the analyst has a good deal of knowledge of ground conditions. Known areas of the image are defined and sampled and assigned a thematic class. Statistics are produced that define each class to be produced. Similar spectral areas are then assigned an associated class in the remainder of the imagery. Unsupervised techniques are used if less information is known about the study site. Algorithms are used in which spectral clustering is performed where the computer assigns pixels of similar spectral properties into separate groups. These groups are then assigned a class using visual, known keys, or ground truth information.

Obviously, there are limitations to what can be derived by remote sensing. Ground truth of study areas are sometimes critical to the assignment of proper land classifications. A major advantage is that what can be classified contains accurate ground location and area representation relative to a certain existing point, line, and polygon data symbology. The methodologies and production costs are known for these themes and will become part of the standard IMAPS list of products that will be available. New data themes include:

- Irrigated agriculture acreage
- Grasslands/grazing lands acreage
- Forestlands
- Fish hatcheries (medium-large areas)
- Strip mining sites (medium-large areas)
- Urban vegetation
- Urban land use
- Nonirrigated agriculture acreage
- Parks (large-medium areas)
- Vegetation types (requires ground truth)
- Water bodies
- Water treatment plants
- Riparian vegetation

The resulting themes will be contained in land use/land cover data layers in the IMAPS database. It should be noted that no associated attribute information will be available for these themes such as ownership, addresses, etc. Landsat Thematic Mapper (TM) scene sizes are 175 kilometers x 185 kilometers and are typically $425 (system corrected)/ $900 (terrain corrected) for the first image and $200 each for additional scenes. RSGIG will purchase and evaluate TM multispectral imagery downstream of Wickiup Dam for a pilot test project to produce examples of these data themes. Making use of this technology will add 3-6 days labor to the average cost of an IMAPS project (depending on themes and accuracy required). Please visit IMAPS website (http://www.rsgis.do.usbr.gov/imaps) for samples and average cost estimates for these themes as they will be posted in the near future.

Future Directions

Remote Sensing and Image Analysis using High-Resolution Image Sources

Higher resolution image primary data sources are becoming available. The Digital Ortho Quarter Quad (1 meter pixel data), which was previously mentioned, has been available for some time. Orthos may be produced from panchromatic or color infrared photography.

Space Imaging's recently deployed commercial IKONOS satellite contains sensors that can produce 1 meter panchromatic and 4 meter multispectral digital images. The applications this system was designed for include utilities management, civil/urban planning, emergency response planning, environmental monitoring, and mining and exploration mapping. Stereo images may be acquired to produce a high-resolution terrain model useful for low-flow flood modeling. Two other high-resolution commercial satellites will be launched within the next year. They are Ball Aerospace/Quickbird and Orbimage/Orbview 3. At present, the IKONOS imagery costs $12 per square kilometer for noncorrected imagery and $75 per square kilometer for terrain corrected imagery. Reclamation receives a 20-percent government discount off this pricing. The additional commercial competition for high-resolution satellite imagery should bring prices down in the long term. Remote sensing, photointerpretation, and image processing of these specific image sources can aid in delineating residential, business activity, and detailed infrastructure and land-use activity that will be very useful in inundation impact analysis.

Satellite images typically contain better consistency in illumination conditions compared to DOQs, which are usually acquired at different dates within a study area. They also contain additional detail because they are archived digitally. DOQS production, in contrast, requires scanning of NAPP photographs. Higher resolution imagery allow entities to be identified in greater detail. These image sources may be processed similar to traditional image sources. However, some applications may not be appropriate for standard per-pixel image classification. The increased information may require ancillary data to be used in a rules-based system to help solve fuzzy situations. These are image classes that may represent more than one possible ground theme. Such an environment may also be known as an expert system. Research is ongoing in developing this area of artificial intelligence.

Some of the themes that are projected to be classified are as follows:

- Bridges
- Strip mines (small areas)
- Dams
- Detailed irrigated agriculture acreage
- Detailed grazing/grasslands
- Tank farms
- Multi/single family residential delineation
- Haz-mat dumps
- Feedlots
- Fish hatcheries (small areas)
- Parks (small areas)
- Irrigation systems
- Detailed nonirrigated agriculture acreage
- Commercial/residential land use activity
- School locations
- Petrochemical plants
- Sewer treatment plants

No associated attribute information will be available for these themes, though more detail may be derived and associations made with existing attributed GIS themes. RSGIG will purchase and analyze (again with the financial help of the Dam Safety Office) both panchromatic and multispectral IKONOS imagery downstream of Wickiup Dam for a pilot test project. The imagery will be evaluated for enhanced manual photo interpretation and automated classification. The additional data layers described above will be produced for this site. Other entities may be identified once analysis commences. Cost estimates will be produced and added to the IMAPS capabilities and products list for future processing at other facilities. Please continue to check the IMAPS website in the future for posted results.

Advanced gray-scale or binary image analysis, texture and pattern recognition, and expert systems may offer abilities to enhance classification of building and infrastructure locations. These are technologies that have not been developed as fully as spectral image analysis or photointerpretation and may require research. Expert system classification of housing and business locations may be evaluated at some point in the future using ERDAS Imagine's expert classifier or similar system if research funds can be attained.

Summary

A variety of new resources and technologies can be brought to rectify positional accuracy problems associated with current government and private digital data resources. Each resource has its own strengths and limitations, but taken together, they can go a long way toward improving data accuracy. These resources, however, come at a cost in labor and materials. RSGIS estimates that making use of these materials can add from 3-9 days labor to the average project, depending upon size, complexity, and process enhancement. Over time, processing can be streamlined, and data and costs will decrease. To date, production costs have been reduced by as much as 50 percent compared to costs after initial development of current capabilities.

Locational Issues That Have Not Been Addressed

Some locational accuracy problems have not yet been addressed. These tend to be specific to the particular data theme to be mapped. *Bridge* data provided by the National Inventory of Bridges, U.S. Department of Transportation, is a case in point. These data come from the States and vary enormously in completeness and positional accuracy. Many bridges simply do not have any associated locational information such as latitude and longitude coordinates. Unless they occur at the intersections of known roads and well-known natural features such as rivers, they can be very difficult and time-consuming to locate. Moreover, while *road* bridge data exist, *railroad* bridge data are difficult to come by. Officials contacted at the National

Inventory of Bridges indicate that as yet the monetary resources and enforcement powers have not been allotted to substantially improve the locational accuracy of their database. Bridges located visually on aerial photography can be noted but will not have associated attribute data.

No suitable national database of *irrigation infrastructure* has been located. Irrigation facilities are sometimes visible on quad sheets, but these may be out of date. Remote sensing and photo interpretation may help in this area. Similarly, facilities are sometimes visible on aerial photography, but again, no attribute data are available. Some facilities have no addresses and are not readily visible on maps or photographs. Underground *mines* fall into this category. Finally, no procedure has been devised to improve the locational accuracy of post office box addresses. The problem, obviously, is that there is a disparity between the postal box location and the actual location of the associated person or business. Thus, while Reclamation's rectification techniques have dramatically improved the positional accuracy of many facilities, they have not improved them all–and may not for some time in the future.

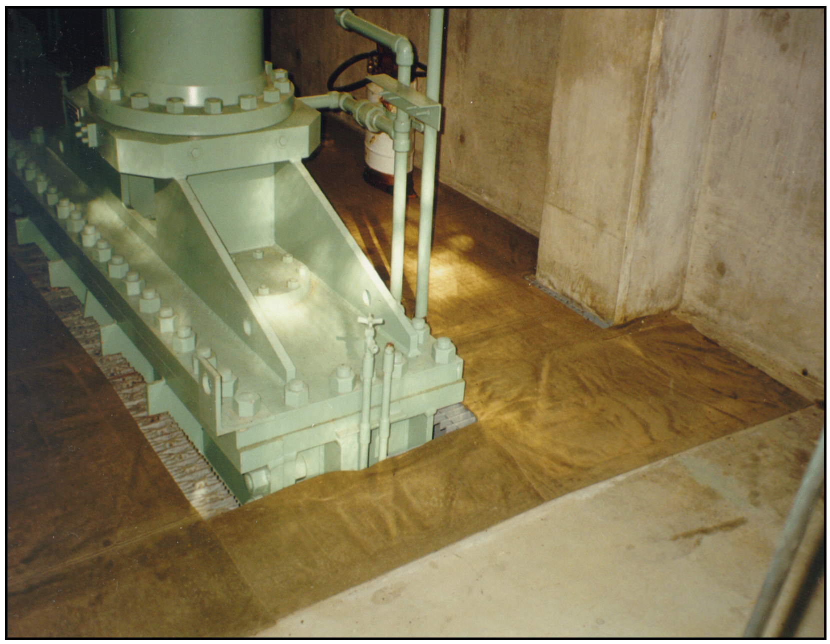
Discussion

In its efforts to automate the mapping and analysis of the impacts of potential dam breach floods, Reclamation has been faced with a variety of positional accuracy challenges. These have included the position of residences and other features within census TIGER line file boundaries; errors associated with incomplete, inaccurate, or noncurrent street addresses; errors associated with hierarchical addressing methods; errors stemming from the imprecise methods and materials of original compilation; and errors arising from the appropriateness of various symbols at various scales. Reclamation has addressed these inaccuracies by bringing to light new graphic data and automated addressing procedures and, in addition, adding a few new data layers—ArcView StreetMap 2000, Digital Ortho Quarter Quadrangles, Digital Raster Graphic Quads, National Aerial Photography Program photos, and the remote sensing and image processing of Satellite Imagery. Each has its own strengths and limitations but, used together, they can alleviate many, if not all, of the positional accuracy issues we have faced. Their use will add some costs in terms of labor and materials to dam breach impact studies. Also, some locational accuracy issues have yet to be fully addressed. Agencies collecting and maintaining these data may need additional financial resources and enforcement authority to upgrade their data quality. Please visit the IMAPS website at http://www.rsgis.do.usbr.gov/imaps for samples and cost estimates for advanced processing and new data themes as they will be posted in the near future.

PROTECTIVE TARPS FOR CONTROL HOUSE OPERATING DECKS

Do you have open grating around your regulating gates that could allow winter slush, hydraulic oil, or other hazardous substances to spill into a lower level or nearby watercourse? At Boca Dam near Truckee, California, the Washoe County Water Conservation District came up with an innovative solution in their control house years ago to help reduce these incidents. The control house for Boca Dam is located at elevation 5500 feet in the Sierra Nevada Mountains along the California-Nevada border.

The control house for the Boca Dam outlet works has two levels: the ground level, which is accessible to vehicle traffic and where the hoist equipment and control panels are located, and the lower level where the jet-flow gates and associated control piping are located. The two levels are separated by open metal gratings surrounding each gate hoist. When the district had needle valves for regulating flows, the lower level of the control house would get extremely cold in the winter months. Whenever the control house doors were opened, cold air would flow into the lower level of the building. The heater for the control house was insufficient to heat the entire area. The damtender bought some canvas tarpaulins and placed them over the open floor gratings. After the needle valves were replaced with jet-flow gates in 1988, the tarpaulins were cut to accommodate the jet-flow gate hoists.



Canvas tarpaulin around jet-flow gate hoist in the outlet works control house at Boca Dam.

This tarp placement can have applications other than as a weather barrier. At a Bureau of Reclamation dam in Colorado, a similar condition exists **only without the tarpaulins.** The damtender spilled some hydraulic oil while performing maintenance on the jet-flow gates, and the spilled oil passed through the open metal grating to the level below. Luckily, none of the oil entered a nearby seepage collection weir that discharged into the river, a blue- ribbon trout stream. Oil-absorbent material was placed over the spill and cleaned up. Had a tarp been laid out across the open metal gratings, the oil spill would have been contained on the tarp for an easier, less risky clean up.

SESSION NOTES FOR WATER MANAGEMENT WORKSHOP
WATER MEASUREMENT, PARTS 1 AND 2

by Brian Hamilton (PN-6439); Jeff Peterson (PN-6438);
Bob Einhellig, Warren Frizell, Tracy Vermeyen, and Tony Wahl (D-8560)

The Need for Accurate Water Measurement

Ever-increasing demands for water by all users are making it critical that water managers accurately account for the water they transport and deliver. Accurate measurement of water is important for many reasons, such as monitoring system efficiencies, determining delivery system losses, measuring the effectiveness of water conservation programs, proper charging of water user accounts, and ensuring fair water distribution to all users.

Since almost all measuring devices not properly maintained or installed will deliver more water than they indicate, improper measurements can be a significant economic loss to the managing organization. It can also mean significant shortages to some users during dry years.

Many districts or water management entities have reached the point where their water supply is no longer sufficient to meet user demands. These entities are now looking for additional sources of water to meet these additional demands. Conservation programs are being undertaken to gain additional water supplies. One of the best water conservation programs that a managing entity can undertake is to increase the accuracy of water measurement. As stated before, inaccurate devices almost always deliver more water than they indicate. When no measuring device is used, estimates are usually made that deliver more water than indicated to reduce the risk of confrontations and arguments. Consequently, significant amounts of water can be "saved" if mutually acceptable measuring devices are used.

Improving water measurement accuracy can also conserve water by reducing operational spills in an open system. The amount of water entering the system to meet demands can be closely regulated so that spills at the lower end of the system can be reduced or even eliminated.

Every cubic foot of water "saved" as a result of improving the measurement of water is more valuable than a similar amount obtained from a new source, if available, because the water saved can be produced at considerably less cost. In instances where new sources are not available, the water saved can be used to meet new demands or provide additional supplies during a drought.

Accurate measurement of water requires proper installation and maintenance of the appropriate measurement device. Selection of the appropriate device can be a critical factor in obtaining accurate results. Using standard devices is best since they are less expensive to operate. Their general use generates more supporting data, thereby making them potentially more reliable.

Standard and Nonstandard Measurement Devices

A truly standard device is one which has been fully described, accurately calibrated, correctly made and installed, and sufficiently maintained to fulfill the original requirements. Standard devices have generally been calibrated in laboratory tests so that standard discharge tables or charts may then be relied upon to provide accurate water measurements. The objective in installation and maintenance of a standard device is to reproduce the same flow conditions in the field as were used during the laboratory calibration of the device. In maintaining a standard device, it is only necessary to visually check a few specified items or dimensions to be sure that the measuring device has not departed from the standard.

Many devices are nonstandard because they have not been installed correctly, and therefore, do not produce standard discharges. Although these commonly used devices may appear to be standard devices, close inspection often reveals that they are not, and they must be calibrated to provide accurate measurements. Thus, proper inspection and care of standard water measurement devices during installation and construction are characteristics of good management.

In rare instances, a nonstandard device is selected for a particular measurement situation, but, more frequently, a district finds itself unexpectedly stuck with a nonstandard device. This happens because a device has been installed improperly, is poorly maintained, is operated above or below the prescribed limits, has poor flow approach conditions, or is the only measuring device available due to lack of funds.

Accurate discharges from nonstandard structures can be obtained only from specially prepared curves or tables based on calibration tests, such as current meter ratings. Calibration tests are tedious and can be quite costly when properly performed. Measurements must be made at fairly close discharge intervals over the complete operating range to fully describe the discharge characteristics. Therefore, it is usually less costly to install standard devices and maintain them in good condition. In checking a nonstandard device, it is difficult to determine whether accuracy is being maintained, except by recalibration.

Measuring devices themselves may be at fault in producing measurement errors rather than the flow conditions. The faults may be divided into two types: those caused by normal wear and tear and those resulting from poor installation.

It is possible to obtain inaccurate discharge measurements from regularly maintained equipment that was properly installed in an ideal location if poor measuring techniques are used by the operator. Measurement of head is very important, and some of the techniques now in use are not suitable for accurate measurements.

Approach Flow

Large errors in discharge can occur because of poor flow conditions just upstream from the measuring device. In general, the approaching flow should be tranquil. Any deviation from a uniform horizontal or vertical flow distribution, or the presence of water surface boils, eddies, or fast currents, is reason to suspect the accuracy of the measuring device.

Sand, gravel, or sediment bars in the approach channel or weeds and riprap obstructions along the banks can cause unsymmetrical approach flow. Other causes may be too little distance downstream from a check structure, turnout, or other sources of high-velocity or concentrated flow; a bend in the channel just upstream from the measuring device; or an eddy which concentrates the flow in part of the cross section.

Turbulence

Turbulence is the phenomenon of relatively small volumes of water moving in a random pattern within the flow mass as it moves downstream. It may be recognized as water surface boils or swirls which appear and disappear in a haphazard way. Because of this local motion within the general motion of the flow mass, any particle of water may at any given instant be moving forward, sideways, vertically, and even backward. In effect, the water is passing a given point with a start and stop motion rather than with a uniform velocity which is ideal for flow measurement. Some turbulence is present in almost all natural and manmade channels and can be tolerated, but excessive turbulence will adversely affect the accuracy of any measuring device.

Poor Workmanship

In contrast with the measurement devices which were once accurate and dependable and have deteriorated are those which, because of poor workmanship, were never a standard device. These include devices which are installed out of level or out of plumb, those which are skewed or out of alignment, those which have leaking bulkheads with flow passing beneath or around them, and those which have been set too low or too high for the existing flow conditions. Inaccurate dimensions can also be the cause of measurement error.

Weathered and Worn Equipment

An unwelcome but fairly common sight on older irrigation systems is a weir blade that was once smooth and sharp but now is in a sad state of disrepair. Edges are dull and dented. The blade is pitted with large rust tubercles. Weir bulkheads are not vertical. Weir blades have sagged and are no longer level. Staff gauges are worn and difficult to read. Stilling well intakes are buried in sediment or partly blocked by weeds or debris. Parshall flumes are frost heaved and out of level. Structures have settled. Exit channels are clogged with vegetation, debris, and sediment. Meter gates are partly clogged with sand or debris, and the gate leaves are cracked and warped. These and other forms of deterioration are often the sources of serious errors in discharge measurements. This type of deficiency is difficult to detect because normal wear and tear may occur for years before it is apparent to a person who sees the equipment frequently. Therefore, it is recommended that periodic independent reviews be conducted.

Measuring devices which are run down are no longer standard measuring devices, and indicated discharges may have considerable errors. To be certain of the true discharge, the devices should be rehabilitated and calibrated.

Proper management of a water measurement device requires keeping up with routine maintenance. However, preventive maintenance is better in terms of public relations and employee morale and, on a long-term basis, is less costly than reactive maintenance done after breakdown or under the pressure of customer complaint.

Most measuring devices, when in rundown condition or improperly installed, deliver more water than they indicate, unless the flow passage is plugged with debris. The very nature of most measuring devices makes it impossible for a device to deliver less water than it indicates. Therefore, water accounting records may not show a proper division between water used and water lost through seepage or waste. Proper evaluation of losses is necessary to establish the economic feasibility of providing canal linings. Canal linings obviously cannot help to recover water lost through poor measuring equipment or procedures.

Exit Flow Conditions

Exit flow conditions can cause as much flow measurement error as some of the approach flow problems. Sharp-crested weirs should always be operated so that the tailwater pool does not submerge the weir blade and so that there is good aeration of the bottom side of the free-flowing nappe. If these two conditions are met, then the weir will operate as a free-flow device, and other flow conditions in the downstream pool cannot affect the discharge rating. On the other hand, flumes and broad-crested weirs can operate either as free-flow devices or with partial submergence. When operating as a free-flow device, exit flow conditions will not affect the discharge rating of the device. However, with partial submergence (i.e., tailwater level above the crest), tailwater conditions can affect the discharge rating. In these flow situations, it is imperative that the submergence not exceed the allowable limit for the device, and the exit channel should be such that flow exits the device uniformly (e.g., not concentrated on one side of the flume due to a bend or other feature of the downstream channel). For some devices, a second water level measurement may be required in the downstream pool if the device is operating under partially submerged conditions.

Faulty Head Measurement

Improper gauge location or an error in head measurement can result in large discharge errors. Readings obtained from stilling wells, whether they are visual or recorded, should be questioned unless the operator is certain that the well intake is not partially or fully clogged. Readings from gauges or staffs which may have slipped should be avoided. Periodic checks of gauges should be made with a level.

Infrequent Measurement

When a head or velocity measurement is made to determine discharge, it can be concluded that the measured discharge occurred only at the moment of the measurement. It cannot be concluded that the discharge was the same even 5 minutes earlier or 5 minutes later. Therefore, water deliveries can be accurate only if enough measurements are made to establish the fact that the discharge did or did not vary over the period of time that water was being delivered.

In many systems, measurements are made only once a day or only when some mechanical change in supply or delivery has been made. Problems introduced by falling head, rising backwater, and gate changes are often ignored when computing a water delivery.

Use of Wrong Measuring Device

Every water measuring device has limitations of one kind or another, and it is impossible to choose one device that can be used in all locations, under all possible conditions. It is to be expected, therefore, that for a given set of conditions, there may be several devices which would be suitable. It is possible that the wrong device was selected in the first place. Whatever the reason, there are instances where accurate measurements are being attempted using a device which cannot, even with the greatest care, give the desired results.

Long-Throated Flumes and the *WinFlume* Computer Program

The term *long-throated flume* describes a broad class of critical-flow flumes and broad-crested weir devices used to measure flow in open channels. These devices are typically the most economical open-channel flow measurement device and are adaptable to a variety of measurement applications in both natural and manmade channels and both new and existing canal systems. The third edition of the *Water Measurement Manual* (see details below) recommends long-throated flumes over Parshall flumes for most new installations due to their low cost, adaptability, and improved accuracy under partially submerged flow conditions. Primary differences between long-throated and Parshall flumes are:

- Long-throated flumes have a control section that is horizontal in the flow direction rather than the inclined floor in the throat of the Parshall flume.

- Long-throated flumes are computer designed and calibrated, allowing the use of custom-designed flumes without the disadvantages previously listed for nonstandard devices (i.e., manual calibration is not needed). The *Water Measurement Manual* also provides tables of standard designs and rating equations that allow for selection and use of long-throated flumes without computer analysis.

The primary advantages of long-throated flumes compared with weirs and other types of flumes include:

- Assuming critical flow occurs in the throat, a rating table specifying the flow rate as a function of the upstream head can be determined with an error of less than 2 percent in the computed discharge. Rating tables can be computed for any combination of a prismatic control section and an arbitrarily shaped approach channel.

- The throat must be horizontal in the direction parallel to the flow but can be any shape in the direction perpendicular to the flow, allowing the complete range of discharges to be measured with good precision.

- Accurate rating tables can be computed using as-built dimensions. The throat section may also be modified as necessary to accommodate changing site conditions, and a new rating can be computed using the modified dimensions.

- The required head loss across the flume is minimal to ensure a unique relationship between the upstream sill-referenced head and the discharge. Long-throated flumes can be operated with partial submergence (i.e., downstream water level above the sill elevation), and the submergence limit can be estimated for any structure placed in an arbitrary channel. Measurement accuracy when partially submerged is superior to that of Parshall flumes.

- Properly designed long-throated flumes can pass both floating and submerged debris.

- Long-throated flumes are typically the most economical structures for measuring open-channel flows.

- Because long-throated flumes can be designed for installation into any arbitrary channel, they are very adaptable to installation in existing canals.

Several generations of computer programs have been available since the mid-1980's for the design and calibration of long-throated flumes. The Bureau of Reclamation (Reclamation) and the Department of Agriculture's Agricultural Research Service (ARS) have most recently written the *WinFlume* program, which operates in a Windows-based computing environment.

This updated software includes significant user-interface improvements and new features and overcomes incompatibilities between Windows 95/NT and the copy-protection system used on the previously available DOS-based software. New features include an improved design optimization scheme, integrated printing of full-scale wall gauges, improved graphics and units system support, and a simplified system for saving, retrieving, and sharing flume designs with other users.

The program can be used to develop rating tables and calibration equations for existing flumes, and the program can also be used to develop new flume designs that meet user-specified design criteria, such as allowable headloss, desired freeboard in the approach channel, and necessary discharge measurement precision.

The new software was formally released in the Fall of 1999 following beta testing by users from Reclamation, ARS, and other agencies. The program and an electronic copy of the user's manual can be downloaded from the Internet at the following URL:

http://www.usbr.gov/wrrl/winflume

The *Water Measurement Manual*

The new third edition of Reclamation's *Water Measurement Manual* is now publicly available (see ordering information below). This revised and updated edition supercedes the 1967 edition and includes several new chapters. Since 1953, Reclamation's *Water Measurement Manual* has been used by designers, system operators, and water users as the primary source for the latest information needed in accurate and reliable flow measurement of irrigation, municipal, and industrial waters.

The staff of Reclamation's Water Resources Research Laboratory collaborated with the staff of the U.S. Water Conservation Laboratory, Agricultural Research Service, to provide state-of-the-art information on flow measurement technology in this third edition. New chapters and sections were added to make the third edition current and more useful to other government organizations. The new chapters cover the following subjects:

- Basic concepts related to flowing water and measurement
- Selection of water measuring devices
- Measurement accuracy
- Inspection of water measurement systems

- Acoustic flow measurement systems

- Discharge measurements using tracers

With this edition, the *Water Measurement Manual* has also become the official manual for flow measurement in the Department of Agriculture.

Reclamation employees can order copies of the *Water Measurement Manual* by contacting the Property Operations Team (Warehouse) in Denver, mail code D-7913, with attention to Todd Marvel. Other agencies and the public can order copies from the Superintendent of Documents, U.S. Government Printing Office, PO Box 371954, Pittsburgh, Pennsylvania 15250-7954, by calling (202) 512-1800, or by fax at (202) 512-2250. The GPO stock number is 024-003-00180-5, and the cost is $34 in the United States and $42.50 for international purchases.

The Water Measurement Manual, as well as other information related to flow measurement technologies, is available on the Water Resources Research Laboratory website at the following URL:

http://www.usbr.gov/wrrl/fmt/

Please feel free to browse this site and give us your comments on how we can better serve your needs.

Mission

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

The purpose of this bulletin is to serve as a medium of exchanging operation and maintenance information. Its success depends upon your help in obtaining and submitting new and useful operation and maintenance ideas.

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