MODELING UNSTEADY FLOWS IN LARGE BASINS: THE SANTA CRUZ EXPERIENCE

V. Miguel Ponce*, Zbig Osmolksi** and David Smutzer***

A case study modeling unsteady flows in a basin in the semiarid Southwest is presented here. The site is the Upper Santa Cruz River basin upstream of the Town of Marana, in the vicinity of Tucson, Arizona. The evaluation uses novel techniques of mathematical modeling in a data-intensive computational environment to calculate frequency-based flows at specific locations. A computer model capable of simultaneously handling the complex topology of the entire basin is driven by 100-year frequency rainfall events of 24, 48 and 96-hour durations.

Introduction

The use of computational methods to evaluate the hydrology of large basins is currently enjoying wide acceptance among practicing engineers and flood hydrologists. For basins exceeding 1000 square miles, the task of simulating flood flows by the computational method can be exceedingly complex. Theestimation of hydrologic abstractions is difficult indeed, in light of the wide range of antecedent moisture conditions. However, other unresolved problems still remain, most notably the choice of spatial and temporal distribution of the input design storm, the channel routing parameters, and infiltration losses through the channel bed.

---

*Professor of Civil Engineering, San Diego State University, San Diego, CA 92182.

**Manager, Flood Control Design, Pima County Dept. of Transportation and Flood Control District, Tucson, AZ 85713.

***Manager, Flood Control Planning, Pima County Dept. of Transportation and Flood Control District, Tucson, AZ 85713.

The Basin

The Upper Santa Cruz River basin drains 3,503 miles in southeastern Arizona and northern Sonora, Mexico. At Tucson, the Santa Cruz River is joined by two major tributaries--the Rillito Creek and the Canada Del Oro--both located downstream of Tucson.

Precipitation varies greatly from year to year, with an annual average of 12 inches per year. Summer precipitation is usually of high intensity and short duration, resulting, as it does, from thunderstorms covering small areas. Winter precipitation is mainly the result of frontal activity, usually covering most of the basin with less intense but longer duration storms. Moisture from tropical depressions located off the Baja Coast of Mexico, combined with low pressure systems in Arizona, also supplies precipitation to the basin.

Most streams in the Upper Santa Cruz basin are ephemeral, being dry for long periods of time. Flow in such streams occurs only in direct response to precipitation, except in isolated cases. The streambeds are extremely permeable, and large amounts of water are lost to the subsurface as the flow moves downstream. The desertic conditions characteristic of the basin are highly conducive to quick runoff, but potential flood peaks are reduced by the relatively large capacity for streambed infiltration.

Case Study

The objective here is to evaluate the hydrology of the Upper Santa Cruz Basin, focusing in particular on the 100-year frequency floods at the Continental (Green Valley), Congress (Tucson), and Cortaro (Marana) USGS gages. These gages have 37, 80, and 44 years of non-continuous record and drain 1,682, 2,222 and 3,503 square miles, respectively. Prior to the October, 1983, flood event, the maximum USGS floods of record were 26,500, 23,700 and 23,000 cfs, respectively.

The Flood

During the last week of September, 1983, a low pressure system originating off the coast of California and a tropical storm moving in from the Gulf of Mexico combined to produce a steady, long duration, widespread rainstorm over southeastern Arizona. Rain gage records indicate that 6 to 8 inches of rain fell over the Santa Cruz and neighboring basins in the six-day period of September 28-October 3, 1983. The event was preceded by the wettest September of Record.

The heavy rainfalls triggered new record flows on the San Francisco River at Clifton (132,000 cfs), the Gila River at Safford, and the Santa Cruz River at Tucson (52,700 cfs). Flood damage caused by the flooding of the Santa Cruz River and tributaries included severe bank erosion which led to structural damage to numerous bridges, the collapse of several homes and businesses which fell into the streams, and overbank flooding which inundated many homes with water and sediment. Overall damage estimates were in the neighborhood of $500 million.

Peak flows during the flood of October, 1983, were estimated by the USGS at 45,000, 52,700 and 65,000 cfs, for the Continental, Congress and Cortaro gages. Due to the washout of the gage during the flood, the Cortaro value is considered only an estimate.

The Model

The modeling approach consists of using a computational hydrologic simulation model to calculate peak flows at the three locations mentioned above, using rainfall events of 100-year frequency. Given the basin's size, the choice of stream channel routing method, and the spatial and temporal distribution of the input design storm and stream infiltration losses are considered the most critical modeling decisions.

Regional rainfall patterns indicate that for a basin of this size, it is necessary to consider both general and local storms. General (winter) storms are usually of low intensity but tend to cover most of the basin rather uniformly. Local (summer) storms cover only portions of the basin, but are usually of high intensity. Rainfall durations are selected to reflect the time of concentration for the entire basin for a 100-year frequency rainfall event. Accordingly, durations of 24, 48 and 96 hours are chosen for the storm simulations.

The model used in this study is a comprehensive modeling system to simulate the rainfall-runoff process in complex watersheds and stream channel networks. The user specifies the network in terms of a set topological numbers. Using this set, the model orders the calculations to enable the subwatershed hydrograph generation and the routing of flows through stream channels and reservoirs. The total basin area is subdivided into upland subwatersheds, which generate upland inflows to the stream network, and reach subwatersheds, which generate lateral inflows.

The model uses SCS methods for hydrograph generation for subwatersheds less than 6.2 square miles. The watershed lag time is based on the curve number method (Soil Conservation Service, 1973). For subwatersheds greater than 6.2 square miles, the time lag is based on the time of concentration. The unit hydrograph duration is based on the time lag. The time-to-peak is based on the unit hydrograph duration. The peak flow is calculated by the SCS synthetic unit hydrograph formula. The synthesized unit hydrograph is convoluted with the effective storm pattern to generate the outflow hydrograph at each subwatershed outlet.

The stream channel routing module is a version of the comparatively recent Muskingum-Cunge method (Ponce and Yevjevich, 1978); therefore, it has the inherent advantage of being physically based. In actual practice, this means that the subreach parameter calibration which is necessary in conventional models (such as Hec-1 and TR-20) is all but eliminated. This enables the modeling of large basins at a level of detail hitherto only possible at a prohibitive cost.

Unlike the classic Muskingum, the Muskingum-Cunge method calculates routing parameters through local flow values, channel cross-sectional characteristics, and overall stream gradients. This enables the flood wave and flow variables, while circumventing the need for large amounts of historic data to ascertain ("calibrate") the values of these parameters. In this way, numerous yet accurate routings are possible.

A unique feature of the channel routing module is its capability to route flows with parameters which vary in time as a function of the local flow values. This is specially indicated for routing overbank flows, since the routing parameters are recalculated every time step to follow the rating curve more closely.

Channel transmission losses are accounted for in the subreach routing process (Ponce, 1979). This feature is particularly applicable to the Santa Cruz Basin where streambed infiltration constitutes an important component of the overall hydrology of the basin.

Data Requirements

The Santa Cruz Basin and stream channel network was configured into 119 reaches and 60 upland watersheds for a total of 179 subwatersheds. Each reach was assigned a topological number and each upland subwatershed a sequential number. Subwatershed areas, stream delineation, hydraulic lengths and stream slopes were evaluated using USGS 7.5' quadrangle maps. Coordinate data for 189 cross-sections was compiled from different sources, including actual field measurements.

Soil and vegetation data were assembled from publications of the USDA Soil Conservation Service and the U.S. International Boundary and Water Commission. These data were evaluated for vegetative cover types, land use and hydrologic condition. SCS methods were used to determine a baseline set of runoff curve numbers. Base flows along the Santa Cruz Basin were considered to be negligible for purposes of simulating flood flows.

Baseline streambed infiltration rates were estimated based on a literature search. Matlock (1965) reported measurements in the range 2-10 ft/day along the Santa Cruz mainstem and for Rillito Creek. A tendency for the infiltration rate to increase with flow velocity--largely because of the higher heads associated with higher velocities and stages--and measured infiltration rates as high as 76 ft/day, but mostly under 20 ft/day. Average infiltration rates of 2-4 ft/day were chosen for the baseline set, to be adjusted during the calibration stage.

Rainfall data for the hindcast simulation included records for 31 gaging stations, spatially distributed throughout the basin. Data for 21 of the stations was hourly, and daily for the remaining ones. Point rainfall data obtained from NWS reference sources indicated that the 100-year frequency, 24, 48 and 96-hour duration storms are 4.6, 6.0 and 6.7 inches, respectively (National Oceanic and Atmospheric Administration, 1973).

Results

Hindcast, general and local storm simulations were performed using a time interval of 7.5 minutes. This interval time was judged to be adequate to satisfy the lag requirements of the smaller subwatersheds. A maximum subreach length of one mile was chosen to match the 7.5-minute time interval and guarantee the numerical consistency of the channel routing (Ponce and Theurer, 1982). The one-mile upper limit on the subreach length triggered the automatic generation of additional cross-sections, up to ten cross-sections per reach in certain cases.

Calibration runs showed the need for a downward adjustment of the curve numbers and an upward adjustment of the infiltration rates. After a series of trials, the values of 44,500, 56,900 and 83,000 cfs were simulated at Continental, Congress and Cortaro gages, respectively, for the October 1983 flood. To accomplish this, it was necessary to reduce the runoff curve numbers by 10 on the average, and to increase the infiltration rates up to five times the baseline values. In light of Woodward's findings (1973), the reduction in runoff curve numbers was deemed necessary to properly account for rainfall duration and corresponding basin size. The calibrated median runoff curve number was 76 and infiltration rates were in the range 2-20 ft/day.

Results of the general storm simulations indicate that the critical storms are of 24-hour duration. Peak values at Continental, Congress and Cortaro are 58,700 45,600 and 55,600 cfs, respectively. These values were obtained by driving the model with low-intensity storm covering the entire basin. Results of the local storm simulations indicate that the critical storms are of 48 hours duration.

Peak values at Continental, Congress and Cortaro are 47,200 cfs, 67,000 cfs, and 47,800 cfs, respectively. These values are obtained by driving the model with high intensity storms covering cells of approximately 400 square miles, critically positioned immediately upstream of the gages.

References

Matlock W.G.
1965 "The Effect of Silt-Laden Water on Infiltration in Alluvial Channels." Ph.D Dissertation, Department of Civil Engineering, University of Arizona. Tucson, Arizona.

National Oceanic and Atmospheric Administration
1973 Precipitation Atlas of the Western United States, Volume VII: Arizona. Washington, DC: U.S. Dept. of Commerce.

Ponce, V.M., and V. Yevjevich
1978 "Muskingum-Cunge Method with Variable Parameters." Journal of the Hydraulics Division, ASCE 104 (December).

Ponce, V.M.
1979 "A Simplified Muskingum Routing Equation." Journal of the Hydraulics Division, ASCE 105 (January).

Ponce, V.M. and F.D. Theurer.
1982 "Accuracy Criteria in Diffusion Routing." Journal of the Hydraulics Division, ASCE 108 (#HY6).

Soil Conservation Service
1973 National Engineering Handbook, Section 4: Hydrology. Washington, DC: U.S. Department of Agriculture.

Woodward, D.
1973 "Runoff Curve Numbers for Semiarid Range and and Forest Conditions." Paper #73-209. ASAE Annual Meeting, Lexington, Kentucky.

THE RISE AND RISE OF THE GREAT SALT LAKE: A CONTINUING LESSON IN THE FLOODPLAIN MANAGEMENT FOR DESERTIC TERMINAL LAKES

Clancy Philipsborn
FEMA Region VIII

As the Federal Hazard Mitigation Coordinator for the two Major Presidential Disaster Declarations in Utah (1983 and 1984), one of my responsibilities has been to facilitate the development, coordination, and implementation of the recommendations of the Federal Interagency Hazard Mitigation Team. Coupled with another responsibility to provide technical assistance to the State of Utah for development of its State "406" Hazard Mitigation Plan, I have become increasingly familiar with the problems of floodplain management in an obscure area, fluctuating lakes.

As a partial consequence of three years of above normal precipitation and excessive groundwater, the Great Salt Lake has risen an unprecedented ten feet in two years. This rise has inundated 625 square miles of perimeter lands, creating enormous economic, political, social, and environmental impacts. Damage estimates to date exceed $176 million.

Although lake level fluctuations are not unusual, historical meteorological and geological records only provide limited indications of what is to come. As the Great Salt Lake continues to rise, it continues to destroy development, fluster its users, and challenge "the experts." Protective and preventive measures have been and will continue to be taken, but additional expected and unforeseen problems arise as quickly as the lake.

The geologic history of elevations for the Great Salt Lake is well documented for the past 25,000 years. Actual recorded historic data, however, date back only to Fremont's observations in 1843. The first gage was installed in 1875. Since that time numerous minor fluctuations have been observed.

Having established that fluctuations of the surface elevation of the Great Salt Lake are not unusual, or unlikely, it logically follows that the astronomical damages resulting from the lake's current level are the result of man having developed in a known hazardous location. At present, damage has occurred to Interstate 80, the numerous mineral extraction industries, private, State and Federal wildlife refuges, power transmission towers, State parks, privately owned resorts, two railroad lines, sewage treatment plants, and housing. Potentially, Salt Lake International Airport and the new International Business Center could be affected. The impacts of this lake rise would be even greater in the absence of the existing consumptive uses (agricultural use of inflow, reservoir retention, and evaporation ponds).

In response to the most recent lake rise, all levels of government have been intensely involved. At the Federal level, the Federal Highway Administration has funded the raising of portions of Interstate 80. The U.S. Army Corps of Engineers has participated in the diking of several sewage treatment plants. The National Oceanic and Atmospheric Administration has maintained precipitation, river inflow, and lake level prediction data. FEMA will be providing funding for the replacement/ restoration of publicly owned damaged facilities, and has maintained a coordination role for the Federal agencies' activities. The Bureau of Reclamation has repaired damaged dikes along Willard Bay. The U.S. Fish and Wildlife Service has diked the Federal migratory bird refuge. The Federal Interagency Hazard Mitigation Team has offered both short and long-term recommendations to all levels of government on how to minimize present and future impacts of Great Salt Lake flooding.

State government has been involved in numerous mitigation projects as well. The Utah Department of Transportation participates in the protective work along Interstate 80, as well as many other inundated roads. The Division of Parks and Recreation has attempted to protect the public parks, beaches, and islands. The Division of State Lands and Forestry, the State Engineer's Office, the Division of Water Resources, the Utah Geological and Mineral Survey (all within the Department of Natural Resources) have performed monitoring and reporting functions, as well as funding at least 17 different studies and plans for immediate response and long-term management of the lake. The State legislature has provided the necessary funding for these projects.

Counties have been involved with selected diking and pumping projects, as have private land developers. The universities and State and Federal agencies have directed selected efforts at improving forecasting techniques in an attempt to reduce the "window of probablity" that future lake levels could be expected to fall within. Present predictions are for the lake to peak at 4210.25 this year, and even higher in 1986.

Valuable lessons in the floodplain management of fluctuating lakes have been learned in the process of responding to, postulating about, planning for, and recovering from the recent rise of the Great Salt Lake. It is important to take note not only of what information has been gained, but also those areas where it appears we have learned nothing. By assimilating and assessing these data sets we better prepare ourselves for similar problems occurring elsewhere, or those that have yet to appear.

Quite simply, we have learned about the enormity of the problem of fluctuating lakes, and the multivariate implications caused by the conflicting land uses in areas that are subject to occasional, repetitive inundation. Scientific investigations into forecasting techniques have led to discussions of El Nino, El Chichon, tree rings, sunspots, groundwater, run-off, precipitation, evaporation, lake effect, drainage, and consumptive use. Economic impacts have affected all levels of government, industry, and private individuals. Multi-jurisdictional political interests are forced upon each other. For example, the Great Salt Lake lies within five different counties, each with their own particular interests, tax base, and set of constituents.

We have also learned of the expanded uses of specific scientific instrumentation and information. There has been identification of new needs to which existing technologies can be applied. There has been the identification of further potential impacts in a host of areas through economic impact studies.

Unfortunately, it is apparent that there are lessons that we have yet to learn.

> [As we know] "The Great Salt Lake lies at the bottom of a closed basin. Due to the wide range of inflow to the lake, the surface level, surface area and volume of the lake has experienced wide fluctuations in the recent past. Efforts have been made to predict future levels of the fluctuations to avoid problems of development around the lake that would be damaged by high lake levels. Recent studies have predicted levels to elevation 4212 in the near future. The general consensus of researchers and climatologists is that such predictions cannot yet be made with any degree of assurance. The data should, however, serve as a warning that the lake could rise to levels that would cause considerable damage to new and existing development around the Lake."

These are the exact words of Lloyd Austin, Division of Water Resources, Utah Department of Natural Resources, in an abstract to his paper, "Lake Level Predictions of the Great Salt Lake." Written in 1979, his words provide an indication of how well his advice has been heeded. Here we are, six years later, repeating the same concerns.

Another point can be made that, even with the recent (past five years) emphasis on nonstructural floodplain management techniques, the only serious response plans considered have been structural, primarily west desert pumping schemes, selective protective diking, and upstream retention and/or diversion. Even the proposed long-term management strategies are based on structural alternatives. These plans merely address lakeshore uses at particular lake level elevations. When all response plans are prefaced by, "From an engineering point-of-view" (inferring a structural response), one cannot help but to think we have a flat learning curve.

I find it ironic that the Southern Pacific Railroad, whose tracks cross the Great Salt Lake on the causeway that contributes to south shore flooding, owns another set of tracks that have been submerged since 1907 beneath the Salton Sea; another fluctuating inland desertic saline terminal lake.

Most important though, we have learned that the rise of the Great Salt Lake is not an unusual event. Across the United States we have found that fluctuating lakes are not unusual. There are documented cases of repetitive flooding from fluctuating lakes in Oregon, California, Utah, North Dakota, Minnesota, New York, and in areas around the Great Lakes. What is disturbing is to find that there has been no semblance of an established methodology, at any level of government, for responding to and planning for these events.

FEMA Region VIII, along with the Natural Hazards Research Applications and Information Center in Boulder, Colorado, are jointly planning to document the responses to these events in order to provide a basis for consistent future policy decisions.

For now though, it is time to institute and implement long-term management strategies for the Great Salt Lake. This event, though unprecedented in its frequency to recur, should not be the problem it is. The problem is not that the Great Salt Lake goes up and down, or that Utah has experienced consecutive years of abnormal precipitation, but that Man has allowed development to occur where maybe he shouldn't have. We accept a certain degree of risk with everything we do. If what we are experiencing now is the risk accepted in the past, then fine, accept it. But let's not make the same mistake twice. Two years from now, or whenever the lake recedes, a long-term strategy should be in place, and enforced. We should define what risk is acceptable to highways, airports, wildlife areas, recreation facilities, private housing, sewage treatment plants, mineral extraction industries, and business and industrial parks, and then direct our future efforts toward operating within those parameters.

* * *

June 1985 Update:

The Great Salt Lake is at its highest level since 1877. On May 21, the lake's elevation peaked at 4209.95 feet ASL. This is 1.6 feet higher than last year at the same time. Since December, Utah has experienced a dry weather pattern with below normal precipitation. Temperatures have been warm and evaporation has increased.

In February, the legislature passed Senate Bill 97 which appropriated $96 million; $20 million to be used for flood mitigation projects and studies and $76 million to be held in a flood mitigation reserve account. One of the lake management options that the legislature is considering is the West Desert Pumping Project. This approach has been determined to be the most effective method to lower the lake level. Four to six pumps would be installed which would pump water from the south arm of the lake through an intake canal to the west pond where the majority of evaporation would occur. The water would then pass through an overflow canal into the east pond. After evaporation, the more concentrated brine would flow by gravity through a canal into the north arm of the lake. In addition to the pumps, dikes would be constructed to protect the Southern Pacific Railroad, the Bonneville Salt Flats, and the Air Force flight training area east of the west pond. Construction of the pumping project would take 15-18 months and cost approximately $52 million. Yearly operation costs would be $4 million. The pumping project would maintain the lake elevation below 4212 feet. During the first year of operation it is estimated that the project would lower the lake by 16 inches. An Environmental Impact Statement is being conducted on the project and should be completed this fall.

Questions have been raised as to the economic feasibility of such a plan. Construction and maintenance of the West Desert Pumping Project are very expensive propositions. It will take 15-18 months for the purchase and installation of special saltwater pumps; by then the lake may be receding. The frequency of the abnormal weather conditions that Utah has experienced the last three years is expected to occur less than once every one hundred years. Concern has been expressed by the State legislature's Energy, Natural Resources and Agriculture Study Committee about private landowners, private roads, mining, and oil claims in the project area. It was also unclear how the brine re-entry into the north arm of the lake would affect mineral extraction industries around the lake, particularly those located on the south shore. For these reasons, alternatives should be carefully considered.

As a nonstructural method to address the lake's rise, the 15-Day Interagency Hazard Mitigation Report recommended the use of a working elevation of 4217 feet for planning and design activities. Scientists at the conference on "Problems of and Prospects for Predicting Great Salt Lake Levels" held in March 1985, also endorsed this recommendation. The State "406" Hazard Mitigation Plan is addressing this issue and is recommending the formation of an Intergovernmental Beneficial Development Council to establish a strategy for planning and development in the Beneficial Development Area, the area between the shoreline and 4217 feet. Meetings were held with State policymakers to brief them on such a proposal. The Great Salt Lake Tech Team, within the Department of Natural Resources, also made this recommendation at their April 18 meeting. They felt that the State should work with the counties to define the floodplain, consider it a hazard area, and plan accordingly. FEMA has informed the State of Utah that damages from future flooding of the Great Salt Lake may not be eligible for Federal Disaster Assistance under PL 93-288.

THE DEVELOPMENT OF RESIDENTIAL STAGE-DAMAGE CURVES FOR APPLICATION IN WESTERN CANADA

Stephen W. Shawcross
IBI Group, Calgary

Augusto R. V. Ribeiro
ECOS Engineering Services Ltd., Edmonton

Introduction

Flood damage estimates are required for evaluating the cost effectiveness of projects designed to alleviate flood impacts. In the past, flood damages have been examined by virtue of three basic techniques: 1) the first entails an examination of the flood plain immediately after the water recedes; if such estimates were available for every flood over a period of many years, a damage-frequency curve could be created; 2) an alternative method is to determine the damage caused by three or four recent floods whose hydrologic frequency can be determined and a smooth damage-frequency curve plotted through these points; 3) the third method entails hydrologically determining various flood elevations for specific flood frequencies and deducing synthetically the damages that would occur given these flood events. This analysis provides a synthetic damage-frequency curve from which one can estimate average annual damages for a given study area.[1] The latter method is the one most frequently utilized primarily due to a number of limitations inherent in the first two techniques, the most critical being that for most flood plains, changes in land use with calendar time prevent the direct usage of a damage-frequency relationship based on historical damages.

Residential stage-damage relationships are an essential component of overall damage estimates. The depth of water above or below the first floor is the most critical estimator of flood damage to the structure and contents of residential buildings.[2] There are several approaches which have been employed to develop residential stage-damage relationships in Western Canada. These are briefly described hereinafter.

Past Studies

The Templeton Curve was developed from actual flood damages incurred as a result of the devastating Winnipeg Flood of 1950. A single generalized curve was derived based upon a fixed percentage of the market values of the structures affected.[3]

A 1975 study of the Fraser River, British Columbia, by the Department of the Environment,[4] estimated damages employing a classification system for categorization of residential units; however, they did not develop a representative stage-damage function for each class and instead employed a fixed stage-damage function based upon the Squamish River Flood Study.[5] Contents were evaluated at 40% of the market cost of the building based upon information provided by the Canadian Underwriters Adjustment Bureau.

IBI/ECOS in a 1980 study of flood damages in Swift Current, Saskatchewan employed the Acres classification system,[6] for determining residential unit types, and indexed stage-damage curves.[7] These synthetic curves of unit depth-damage relationships for residential structures and contents were developed for the Joint Task Force on Water Conservation Projects in Southern Ontario in 1968 by Acres. The Curves were derived from field surveys of a representative sample of various unit types located within the City of Galt (Cambridge).

Stage-damage curves produced by the Federal Insurance Agency in the United States, (FIA Curves), which are premised on actual flood damage claims by unit type, have been employed on a number of other flood damage reduction studies undertaken in Alberta.[8,9]

The Fort McMurray Flood Damage Reduction Study

In 1981 the Alberta Department of the Environment, which is the provincial agency responsible for the management of water resources, initiated a comprehensive study of flood damages for the City of Fort McMurray in northeastern Alberta. A subsidiary objective of the study was to develop stage-damage curves that could be applied on future flood damage studies undertaken throughout

Alberta. An important component of the study was the evaluation of past estimation techniques. This review raised a number of concerns regarding use of these data: 1) With respect to the FIA Curves, there is no adjustment factor developed for application to Canadian situations. As well, this approach requires individual market appraisals of each unit and finally, basement damage is not adequately considered; 2) Regarding the Templeton and Acres data, this information was 30 and 16 years old respectively; needless to say, construction techniques as well as content types and distrubutions had changed considerably since the curves were initially developed. In addition, these data sources did not adequately consider different housing types i.e. 1 storey, 2 storey, split-level, etc.

Context

The City of Fort McMurray, with a population of 34,000 people, is located at the confluence of the Athabasca and Clearwater Rivers in northeastern Alberta. The oldest developed areas of Fort McMurray, the Lower Townsite and Waterways, are situated in the floodplain of the Clearwater River and have a history of flooding which dates back to 1835. The severest flooding is associated with the occurrence of an ice jam on the Athabasca River and the last major flood in 1977, which approximated a 1:17 year event, caused damages in the order of 20 million dollars.

Inventory of Residential Structures

A total of 3,341 residential units were inventoried and classified according to basic quality (A,B and C) and unit type (1 storey, 2 storey, split level). The classification system (See Exhibit 1) was also expanded to reflect several categories not addressed in previous studies i.e. mobile homes and multi-family dwellings.

Content Damage Curves

Individual content damage curves were derived for each classification and unit type based on a detailed contents survey of a statistically significant number of residential structures. The survey was directed toward obtaining up-to-date total depreciated contents per residential category. Survey questionaires were operationalized for easy computerization and a content damage program was developed. The extent of direct flood damages to various objects as well as restoration costs for flood damaged items were determined through consultation with experienced service and repair establishments. Ninety-five percent (95%) confidence limits were calculated for each structural type and for the overall sample of 124 units. The 95% confidence limits for the various structural types ranged from ± 11.7% to ± 26.6%. However, the 95% confidence limits for the entire sample were ± 8.6% of the mean total content value (See Exhibit 2).

EXHIBIT 1

FORT McMURRAY RESIDENTIAL CLASSIFICATION SCHEME

Class	General Description
AW 1* AW 2 AW 3	Typical custom constructed housing built, for the most part, during the 1970's architecturally designed with control of materials selection and consideration of increased insulation values vapour seals, passive and active solar heating systems Interior materials, finishes and general decor reflect an above average upgrading to the personal requirements of the owner These houses represent the high end in terms of real estate values
BW 1 BW 2 BW 3	Typical subdivision construction of the 1960's, constructed by the developer or builders from a selection of stock design plans in accordance with design guidelines for exterior materials control Exterior materials are typically aluminum and wood siding, stucco and brick veneer The size of the unit, style and lot size set the average real estate value These houses have average insulation values and represent middle real estate values
CW 1 CW 2 CW 3	Typically constructed during the 1940's to 60's, units are of average design, less than average m^2 (≤300), have a low level of insulation value, no vapour barrier or vapour seal and generally have exterior finishes of wood siding and stucco Generally these units are located in the core area have a high land to building value ratio and represent the lower end real estate values Many units will have upgraded interior finishes
D 1 D 2 D 3 D 4	Mobile Home, Double Wide - Good Quality Mobile Home, Double Wide - Poor Quality Mobile Home, Single Wide - Good Quality Mobile Home, Single Wide - Poor Quality
MA	Apartment Towers
MW	Walk-up Apartments, Row Townhouses

*1 2 3 denotes 1 storey, 2 storey and split level respectively

EXHIBIT 2

MEAN TOTAL CONTENT DAMAGE BY STRUCTURE TYPE

Structural Type	Mean $ (1982)	Standard Deviation	Sample Size	95% Confidence Limits
BW	7983 56	2627 34	34	$\bar{x}$ ± 11 7%
CW	4703 28	1996 31	26	$\bar{x}$ ± 17 5%
DW	5554 79	2090 22	22	$\bar{x}$ ± 17 1%
MA	4989 19	2106 89	13	$\bar{x}$ ± 26 6%
MW	3513 39	1170 89	29	$\bar{x}$ ± 12 9%
ALL	5505 48	2668 73	124	$\bar{x}$ ± 8 6%
BW,CW,DW,MW	5565 95	2721 04	111	$\bar{x}$ ± 9 2%

Structural Damage Curves

The structural characteristics of residential units in each class were determined through field inspection by qualified architectural personnel and consultation with the local building industry. For each unit type, average square footage, perimeters, length of interior walls and types of finishes were calculated. Estimates of unit prices for replacing and/or repairing flood damaged materials were obtained from local suppliers and contractors. Based on the house characteristics and unit prices, damage for each foot of flooding was estimated for each unit type within the three basic categories (A,B, and C).

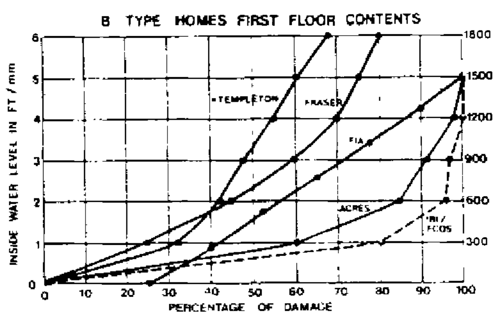
Comparison of Damage Curves

As part of the overall analysis, a comparison was made between stage-damage functions developed for previous investigations of flood damages, as discussed, and those developed specifically for the Fort McMurray Study. (See Exhibit 3). Damages were generated for the study area using the various curves. The following are the major observations of this analysis: 1) average annual damages employing the Fort McMurray Curves (IBI/ECOS) are significantly higher than those utilizing the other curves. This is directly related to substantially higher contents damages sustained at lower flood levels; 2) as average annual damages are highly sensitive to the stage-damage relationship, curves that do not accurately depict this relationship (FIA, Fraser, Templeton) could be grossly underestimating damages. While the Acres Curves approximate the Fort McMurray distributions, total damages indexed to 1982 values were substantially lower due to significant changes in residential content types, values and distribution since these curves were developed in 1968.

EXHIBIT 3

COMPARISON OF DIMENSIONLESS

STAGE - DAMAGE FUNCTIONS



*Includes Structure and Contents Damage

Conclusions

A number of major conclusions were drawn from this study as follows: 1) For most Western Canadian situations the previously developed stage-damage curves (Acres, FIA, Templeton and Fraser River) are not expected to render accurate assessments of damages for benefit-cost purposes; 2) Additional surveying of residential units from various sized centres across the Western Provinces should be undertaken in an effort to develop regional stage-damage curves; 3) In the absence of this data it is proposed that with indexing to account for regional and provincial economic differences the curves developed for Fort McMurray could be applied throughout Western Canada; 4) Unit stage-damage relationships should be updated at regular intervals to ensure they accurately reflect current trends and conditions.

References

1. James, L.D. and R.R. Lee
   1971 Economics of Water Resources Planning, McGraw-Hill Series in Water Resources and Environmental Engineering, New York: McGraw-Hill

2. Davis, A. Stewart
   1981 User's Guide to the Federal Insurance Administration's 1978-1979 Flood Claims File for Computation of Depth-Damage Relationships, U.S. Army Corps of Engineers, Virginia.

3. Templeton, C.
   1960 Benefit-Cost Analysis of the Greater Winnipeg Floodway, The Proceedings of the Engineering Institute of Canada, Annual General Meeting, Paper No. 34.

4. Book, A. N. and R. Princic
   1975 Estimating Flood Damages in the Fraser River Basin, Environment Canada, Inland Waters Directorate, Pacific Region, Water Planning and Management Branch.

5. Canada Department of Energy, Mines and Resources
   1967 Squamish Benefit-Cost Study, Unpublished Report, Engineering Division, Inland Waters Branch.

6. Acres Ltd.
   1968 Guidelines for Analysis, Vol 2. For the Governments of Canada and Ontario, Joint Task Force on Water Conservation in Southern Ontario.

7. IBI Group and ECOS Engineering Services Ltd.
   1981 City of Swift Current Flood Plain Management Plan, Canada-Saskatchewan Flood Damage Reduction.

8. Proctor Redfern Butler and Krebes
   1979 Fort McMurray Flood Damage Estimates, Alberta Municipal Affairs, Fort McMurray.

9. The Dalcor Group
   1979 Drumheller Flood Control Study, Alberta Environment, Calgary.

10. IBI Group and ECOS Engineering Services Ltd.
    1982 Phase IIB, Flood Damage Estimates, Fort McMurray Flood Damage Reduction Program, Technical Report, Alberta Environment and the City of Fort McMurray, Fort McMurray.