An Assessment of Flows for Rivers

of the Great Lakes Basin

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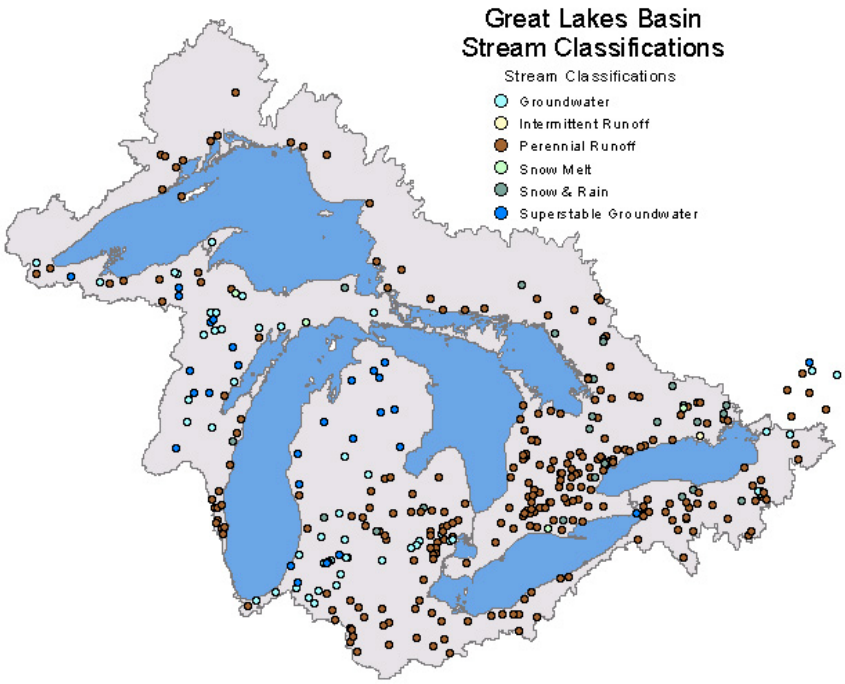

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Executive Summary

River flows, typically measured in cubic meters or cubic feet per second, vary in the magnitude, duration, and frequency of flow events, in the predictability of their timing, and in their rate of rise and fall. A hydrograph, or plot of discharge vs. time (often, days) depicts these changes visually. Variation in river flow can be quantified using a variety of statistical methods, providing a description of the *flow regime* of a river or river segment. Flow regime in unaltered rivers is a function of climate, geology, vegetation and topography. Prior research strongly supports the concept that river flow regimes fall into recognizable classes, and those classes of river flow vary across the nation.

In addition, human actions alter the flow regime in diverse ways. In general, dams and impoundments reduce daily and seasonal fluctuations; this is referred to as river regulation. Impervious surfaces, stormwater conveyances, farm tiles, and drainage ditches all speed runoff into receiving waters, resulting in more event-responsive hydrographs. Alteration of flow regime can adversely affect the physical, chemical, and biological condition of a river. Ecological restoration of rivers thus requires some knowledge of the natural flow regime of a river, and of the extent of its alteration.

The goal of this project is to investigate the concept of the flow regime as applied at the scale of the Great Lakes basin. Specifically, this project asks three questions: (1) can we characterize the flow regimes of the rivers of the Great Lakes basin? (2) have flow regimes changed over time, specifically between early and late in the 20th Century?, and (3) what have been the roles of climate change versus human actions in causing the observed changes? In addition, this project has developed a customized project for the Arc View 3.x geographic information system (GIS), which allows the user to construct hydrographs, retrieve information about dams, and access contact information for governmental and non-governmental organizations associated with the watersheds of the Great Lakes.

The characterization of flow regimes of rivers of the Great Lakes basin employed a total of 425 gages (259 in U.S., 166 in Ontario) and the most recent (to 1998) 20 years of continuous streamflow records. Numerous measures of flow were computed using the Indices of Hydrologic Alteration (IHA) software, and each river was assigned to a flow regime using a decision tree. These analyses support the view that flow regimes can be characterized for rivers of the Great Lakes Basin. The majority (70%) of rivers fall in the perennial runoff category of Poff (1996), a further 22% are stable or super-stable, and the remainder are in snowmelt or snow and rain categories. Inspection of the spatial distribution of flow categories reveals that perennial runoff streams are found throughout southern Michigan, southeastern Ontario, and in tributaries closely ringing the Lakes. Stable and super-stable streams occur most frequently in Michigan's Northern Lower Peninsula, and less frequently in the Upper Peninsula. A map of flow regimes for the streams of Michigan, when superimposed on the State's geology, reveals the strong influence of geology, and especially of slope and permeability, on flow regime. These results support and extend a prior analysis by Richards (1990), demonstrating strong regional streamflow patterns within the Great Lakes basin.

Numerous components of the flow regime were found to change over the 20th Century. A comparison of streamflow statistics for two distinct 20-year records, ending

ca.1950 and 1998, for 53 sites in Michigan, documented numerous changes in IHA metrics. Increased runoff and flow magnitude (both high and low) measures likely are attributable to an overall increase in precipitation, whereas increased predictability of timing may reflect the cumulative impact of dams. The faster rate of rise, well illustrated by a case study of the Huron River, is best attributed to increases in impervious surface and stormwater conveyance.

Dams fragment river systems into disconnected units, breaking the natural continuum of inter-connected processes and making fish passage difficult or impossible. Both federal and state data bases contain dam inventories. The National Inventory of Dams, which includes some 75,000 dams (U.S. Army Corps of Engineers 1996), may seriously underestimate dam density. Criteria for inclusion in the NID database include: dams > 2 m (6 ft) high with storage > 61,700 m^3 (50 acre-feet), those > 8 m (25 ft) high with storage > 18,500 m^3 (15 acre-feet), and those of any size that pose a significant human risk. Inventories from State Dam Safety Programs indicate that the "true" number of dams may be twice that recorded in the NID.

A previous study (Graf 1991) calculated dam density as drainage area per dam for 18 regions of the USA using the NID database. That estimate for the Great Lakes basin was 223 km^2 of drainage basin per dam. When the same calculation is made for Michigan, using the State dam database, the estimate is 63 km^2 per dam. Clearly, river systems are considerably more fragmented by dams than is indicated by prior analyses that focused only on large dams.

The customized ArcView GIS project included with this report allows the user to construct hydrographs, retrieve information about dams, and access contact information. It is a pilot project that demonstrates the opportunities for information dissemination regarding Great Lakes data layers, specifically those associated with river flows and dams. The internet has matured to the point where it is now ready to effectively handle geographic information and mapping. A logical next step for this material is to house it on an internet-enabled server for easier updating and instant distribution to a wider audience. From there, users would also be able to take advantage of information integration programs being developed for the U.S. and the Great Lakes region, including programs in individual states, across lake basins and at the federal level, allowing updates to contact information, additional agency links, and the immediate inclusion of additional or more refined data as these become available.

Ultimately, re-establishing more natural flow regimes in the rivers of the Great Lakes Basin is a core element of a larger strategy to protect and restore the health of waters of the Great Lakes ecosystem, leading to improvements in the physical environment and restoration of biological health. While dams, water withdrawals, and other direct physical modifications to free-flowing rivers are important, the more subtle influences of altered land use should not be neglected. By identifying the flow regime characteristics of rivers of the Great Lakes Basin, this report contributes to on-going efforts to improve water management for humans and for ecosystems of the Great Lakes.

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Introduction

There is no question that rivers and their biota have suffered greatly from alteration of flow regimes (Poff et al. 1997, Postel and Richter, 2003), and by fragmentation of river habitat by dams (Benke 1990, Dynesius and Nilsson 1995) and the less well-publicized influences of culverts and other blockages. Just as rivers and their flow regimes exhibit regional patterns (Poff 1996), so do the extent and severity of these threats. Studies in Midwestern rivers document a strong relationship between flow regimes and fish assemblages (Poff and Allan 1995, Zorn et al. 1998). However, there has been no systematic evaluation of the extent of alteration of the flow regimes of rivers of the Great Lakes basin, or of the influences on the biota, at the scale of the region. Multiple factors can influence flow regime, and in many circumstances changing land use may be of greater importance than dams and other in-channel modifications. Decision-makers, managers, and granting institutions cannot adequately target restoration approaches without a firmer understanding of the extent and influence of flow alteration in rivers of the Great Lakes basin.

The concept that an unaltered river has a natural flow regime, that human activities alter river flow in diverse ways, and that channel shape, habitat for the biota, and ecological integrity can suffer due to a variety of human activities is now well established (Poff et al. 1997). As a consequence, efforts to restore a river's flow to more closely resemble its natural condition have become a cornerstone of river restoration (for example, see The Nature Conservancy's Sustainable Waters Initiative at http://www.freshwaters.org/, and American Rivers website at http://www.amrivers.org/

The flow regime concept can be illustrated by analogy to climate. Just as Chicago has a different climatic regime than San Francisco, so do individual rivers differ in their annual cycle of flow. Rivers originating in the snowpack of the Rocky Mountains have a characteristic spring run-off associated with snowmelt, while rivers of Western Oregon experience high, but highly variable, run-off throughout winter and spring due to their high precipitation and mild winter climate that fluctuates above and below freezing. Some rivers of the southeastern United States experience high flows in any month of the year, and some rivers of the northern Lower Peninsula of Michigan are highly stable because the soils of their watersheds are so permeable that most precipitation drains directly to the water table, buffering streamflow from storm-driven run-off. The amount and timing of precipitation, whether winter temperatures are sufficiently cold for development of a snowpack, the topography of terrain and permeability of soils, along with vegetation and its influence on water loss via plants, all influence the flow regime of a river.

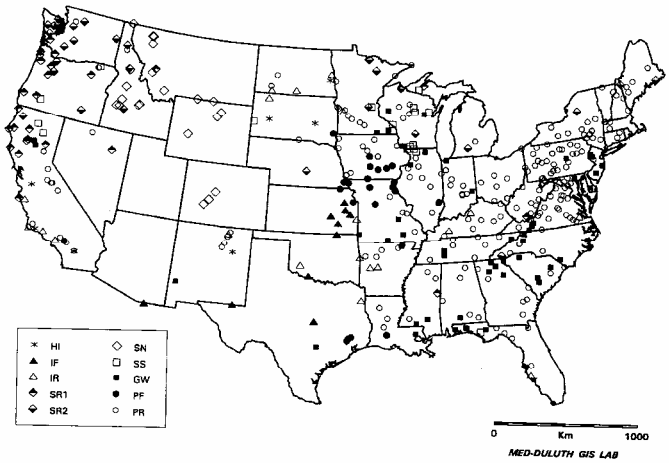


Figure 1. A national classification of flow regimes, from Poff (1996). HI, harsh intermittent; IF, intermittent flashy; IR, intermittent runoff; SN1, SN2 snowmelt; SR 1, SR2, snow and rain; SS, super-stable groundwater; GW, stable groundwater; PF, perennial flashy; PR, perennial runoff.

A national categorization of river flows (Figure 1) identified nine categories of river flow (Poff 1996). While this analysis suggested some reasonable geographic patterns to flow regimes (e.g., the clustering of intermittent streams in the southwest, and of snowmelt-driven streams at higher latitude and elevations), the coverage is inadequate to assess regional patterns at the scale of the Great Lakes basin.

Flow regime can be characterized using a variety of approaches to quantify the timing, predictability and range of variation of flows. Analysis of annual peak flows can be used to determine the size of a flood that is expected to occur at, say, a ten-year interval. Analysis of daily flows allow estimation of a discharge that might be equaled or exceeded 10 % of the year (i.e., on 36 occasions) – this is referred to as a Q_{10}, and is a high-flow index, whereas the Q_{90}, a flow equaled or exceeded 90% of the time, is a low-flow index. Increasingly, flow analyses make use of the Index of Hydrological Alteration (IHA) software (Richter et al. 1996). The IHA uses a long-term (typically 20+ years) record of daily streamflow to calculate a number of indicators, which reflect the magnitude, frequency, duration, timing, and rate of change of flow (Figure 2). Moreover, flow regime is envisioned as a master variable that influences other key suites of variables contributing to overall stream health (Poff et al. 1997).

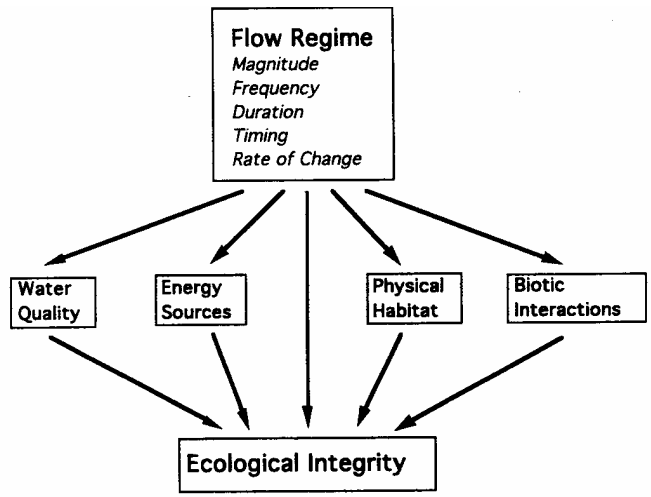


Figure 2. Flow regime as a master variable. Flow regime is of much interest for management and restoration because it is thought to influence stream ecosystems in multiple ways, and its components are potentially accessible to scientific inquiry and to management action

Human activities alter flow regimes in many ways. Dams impound flood waters for later use, whether for hydropower or for agricultural and municipal use. In extreme cases the river is completely regulated, meaning that its hydrograph shows little daily or seasonal variation. Other human actions hasten the flow of storm water into streams, causing more rapid run-off and flooding than would otherwise occur. Changing land use, impervious surfaces, storm drains, drainage canals, farm tiles and seasonal removal of vegetation (e.g., plowing under of crops) all create more responsive or “flashy” flow regimes, while also lowering baseflow because groundwater recharge is reduced (Poff et al. 1997).

Objectives

The goal of this project is to investigate the concept of the flow regime as applied at the scale of the Great Lakes basin. Specifically, this project asks three questions: (1) can we characterize the flow regimes of the rivers of the Great Lakes basin? (2) have flow regimes changed over time, specifically between early and late in the 20th Century?, and (3) what have been the roles of natural climate change versus human actions in causing the observed changes? In addition, this project has developed a customized project for the Arc View 3.x geographic information system (GIS), which allows the user to construct hydrographs, retrieve information about dams, and access contact information for governmental and non-governmental organizations associated with all watersheds of the Great Lakes.

Analysis

Suitable Gage Sites

While a flow analysis can be performed on any reasonably long run of streamflow data, and there are approximately 7,000 gages in the United States (including active and discontinued gages, NRC 2004), characterization of the flow regime for a region requires that gage sites from heavily modified locations be excluded. Poff's (1996) analysis, based on very rigorous criteria, utilized fewer than a dozen gages from the U.S. Great Lakes basin. This report is based on an analysis of 425 U.S. and Canadian gages out of the nearly 700 total. All candidate gages were screened to ensure a minimum of 20 years of continuous data, up to 1998, and that the influence of dams and development were not excessive (Figure 3).

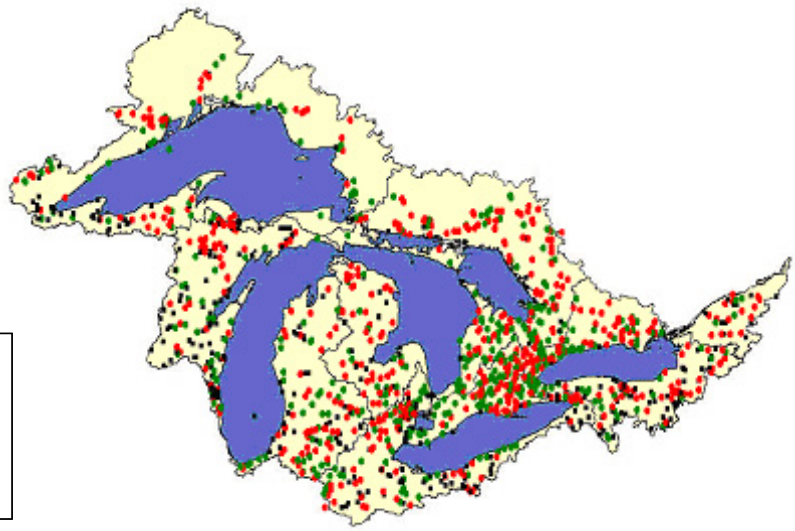


Figure 3. The 425 gages (259 in U.S., 166 in Ontario) included in analyses. Gages were excluded due to incomplete records or obvious flow regulation.

Legend:

- Regulated Gages
- Natural Gages
- No Information Available

Flow Regimes of Great Lakes Basin Rivers

The characterization of flow regimes of rivers of the Great Lakes basin employed a total of 425 gages (259 in U.S., 166 in Ontario) and the most recent (to 1998) 20 years of continuous streamflow records. Numerous measures of flow (see Figure 2) were computed using the IHA software, and each river was assigned to a flow regime using the decision tree of Figure 4.

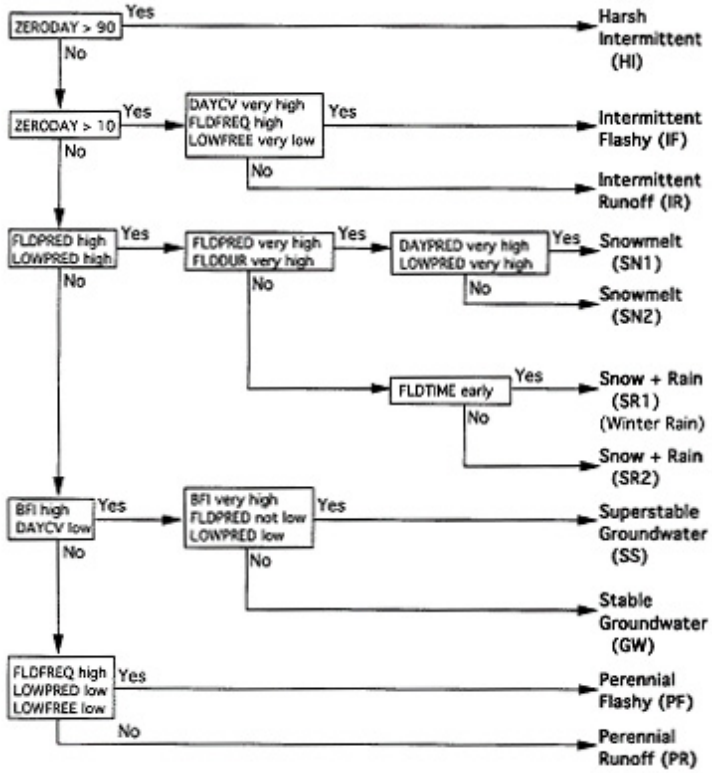


Figure 4. The decision tree developed by Poff to assign individual streams to their flow regime based on numerous measures of streamflow (e.g., days of zero flow, daily coefficient of variation, predictability of low flows and flood flows, etc.). (See Poff 1996 for details).

Stream flows at the 425 gages were assigned to the following six categories. Some 70% (264) were categorized as perennial runoff, by far the most common category. Another 22% were placed in one of the categories of very stable stream flows (stable groundwater, 14%; superstable, 8%). The remaining categories included snow + rain, 7% (25); snowmelt, 1% (4); and intermittent runoff, 0.3% (1). Despite the reputation of the Great Lakes Basin for cold winters, because precipitation is fairly evenly spread over the year, and periodic thaws occur throughout winter at many locations, snowmelt hydrographs are rare. Most streams exhibit perennial runoff, although a substantial minority are stable to very stable.

The Geography of Flow

Whether the various categories of stream flow occur randomly throughout the Great Lakes Basin, or exhibit geographic clusters that might be indicative of broad geologic and climatic controls, can be investigated by examining a map of flow regimes.

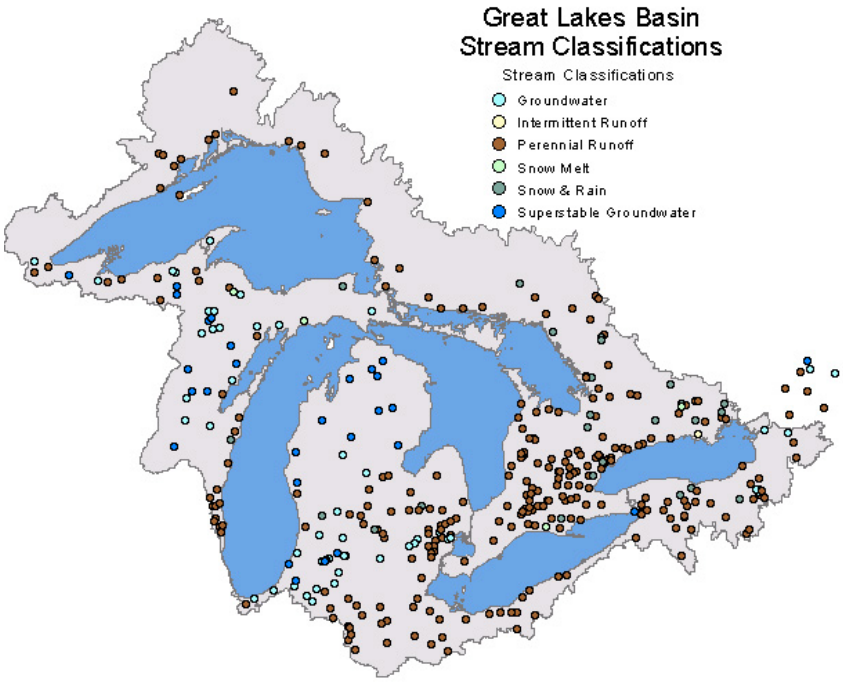


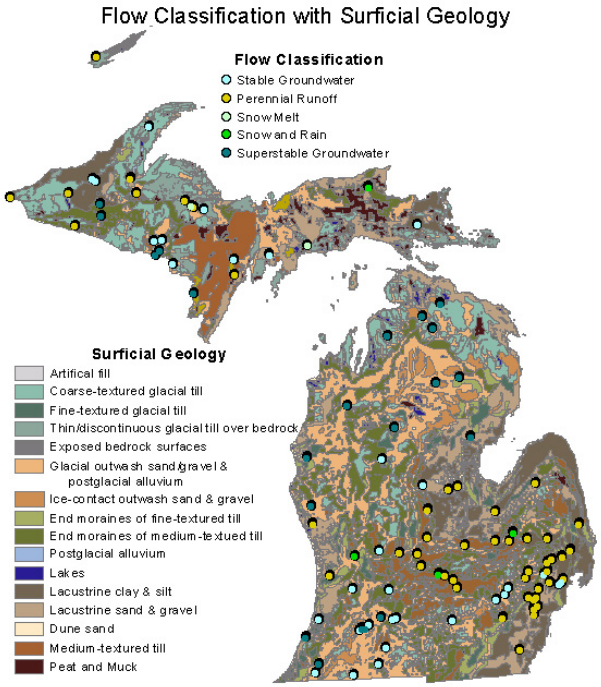
Figure 5. A stream classification of the Great lakes basin, based on analysis of flows at 425 gages. Most (70%) streams are perennial runoff, another 22% are stable or super-stable, and a small percentage reflect snow melt or snow and rain hydrographs.

Inspection of the spatial distribution of flow categories reveals that perennial runoff streams are found throughout southern Michigan, southeastern Ontario, and in tributaries closely ringing the Lakes (Figure 5). Stable and super-stable streams occur most frequently in the Northern Lower Peninsula, and less frequently in the Upper Peninsula.

The likely influence of geology on runoff is illustrated for Michigan by an overlay of flow regime classes on a map of the surficial geology of the State (Figure 6). In particular, the stable and super-stable sites tend to cluster near morainal regions of the Northern Lower Peninsula, where the high infiltration capacity of gravel and sandy soils allows most precipitation and melting snow to drain directly into groundwater. As a consequence, stream flows are very stable, and the response of runoff to storm events is muted. In contrast, the area of southeastern Michigan, as well as near Saginaw Bay, is flat and composed of less permeable silts and clays, resulting in many stream flows that are more responsive to storm events.

This analysis agrees well with a prior flow categorization by Richards (1990), who found high flow variability in the western and central Lake Erie drainage basin, and low flow variability in most tributaries draining the northern Great Lakes watershed.

Figure 6. Streamflow classification, superimposed on the surficial geology of Michigan, illustrating the association of certain stream flow classes with specific geology. Map from Farrand and Bell (1982)



Changes to Flow during the 20th Century

Components of stream flow may have changed over the course of the 20th Century due to natural events, including a wetter or drier climate, and to human influences, including dams and changing land use. By comparing flows early and late in the 20th Century using gages with long-term records, it is possible to detect changes and make inferences as to probable cause.

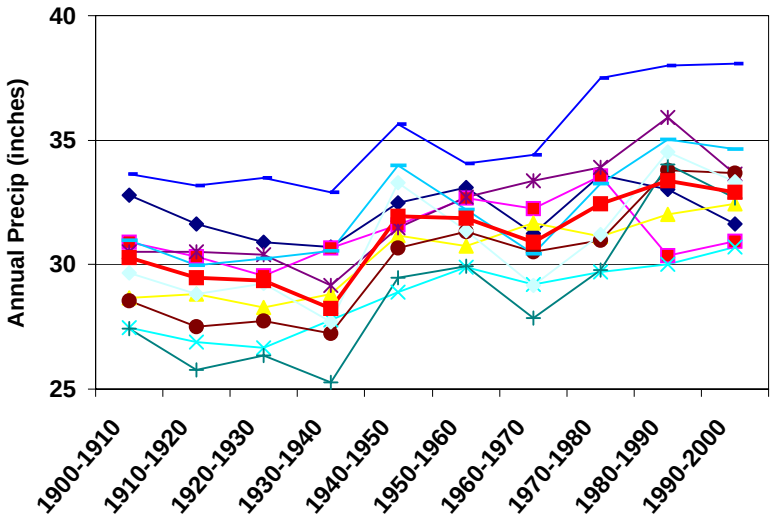
This analysis selected 53 gages within Michigan, and compared the earliest 20 years of record, starting before 1950, with the most recent 20 years of record that included WY1995 or later. The time intervals were contrasted by paired t-test.

Some 27 of 42 measures of hydrologic regime in the Great Lakes Basin revealed changes in Michigan between the first and second half of the 20th C. Magnitudes generally increased, as did predictability of flows. There are more high flow and fewer low flow events, and the low flow events are of shorter duration. Base flow and minimum flows have increased, but maximum flows have not changed detectably. The rate of rise of flow is significantly faster than was true earlier in the record.

It is difficult to determine what fraction of this change is due to natural events and what fraction might be ascribed to human activities, and it is likely that both contribute. Two lines of evidence implicate a trend towards greater precipitation over the 20th Century (for independent evidence of this trend see http://yosemite.epa.gov/oar/globalwarming.nsf/content/ClimateTrendsPrecipitation.html).

First, water yield (annual runoff per unit area) has increased between the time intervals, suggesting increased runoff, which may be due to higher precipitation, or possibly due to more impervious surface and reduced evapotranspiration. An increase in high flow events may have the same cause. Figure 7 depicts annual rainfall over the 20th Century, averaged by decade, for ten regions of Michigan. A distinct upward trend is evident.

Figure 7. Annual precipitation for ten regions of Michigan, averaged by decade. Bold red line is the average for all regions.



Other changes in flow likely are due to human influence. The cumulative effects of dams likely is responsible for making flow more predictable through storage, and also may contribute to increased minimum flows by releases during low-flow periods. The cumulative effects of impervious surface and water conveyance likely account for the increased rate of rise of flows and contribute to the increase in flow magnitudes. Because the influence of flow regulation by dams and increased runoff due to impervious surface and water conveyance are off-setting, there may be some tendency for each to mask the influence of the other in the flow metrics analyzed. Finally, the trend towards greater precipitation over the 20th Century (Figure 7) may be natural or a reflection of human-induced climate change.

A case study of the Huron River provides convincing evidence that the river's rate of rise and fall is more abrupt than previously thought. The record for the Huron River at Ann Arbor (1915 to present) was broken into the periods 1915 – 1950, and 1960 – 1998. This division was chosen to separate the period of rapid development post WWII from the earlier period. Using the IHA and following an approach developed by Brian Richter of The Nature Conservancy (personal communication), flow metrics were computed for the period 1915-1950. These values were ranked and then divided into equal thirds, thus establishing the ranges for the lower, middle, and upper third of the data for the early period. The same metrics were then computed for the period 1960 – 1998. Finally, the observations from the more recent record that fell within the lower, middle and upper thirds of the earlier record were determined.

The Huron River case study (Figure 8) illustrates the utility of this approach. Compared with 1915-1950, the rise rate of stream flow over 1960 – 1998 very rarely falls in the lowest third established earlier in the 20th Century, whereas most estimates fall in the highest third of values established earlier. This is a strong indication of more rapid routing of storm flows into the river. The fall rate also shows a trend towards higher values later in the 20th Century, although the shift is less dramatic.

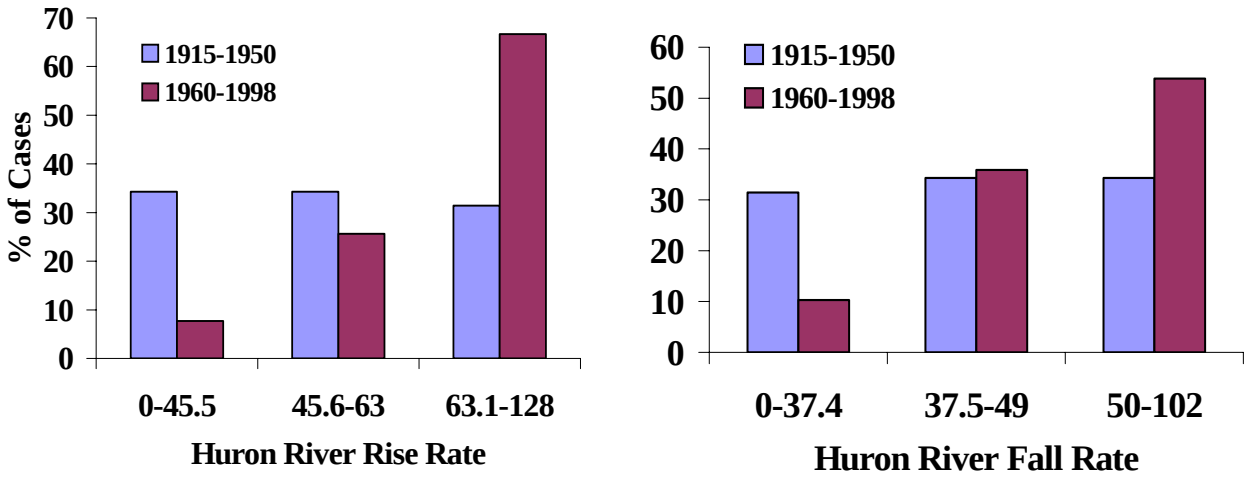


Figure 8. A comparison of the rate of rise and fall of the Huron River between the first and second halves of the 20th Century. Values from 1915 – 1950 are used to establish the range (lower, middle, upper third) prior to extensive urbanization. Values from 1960-1998 fall with disproportionate frequency in the upper third of values derived from pre-1950.

Damming the Rivers of the Great Lakes

Dams fragment river systems into disconnected units, breaking the natural continuum of inter-connected processes and making fish passage difficult or impossible. Most of the large rivers of North America are fragmented by dams (Dynesius and Nilsson 1994, Graf 1999). Of more than 5 million river km in the conterminous USA, only about 42 rivers longer than 200 km remain relatively natural and undammed (Benke 1990). In addition to fragmenting river systems, dams affect river ecosystems by altering flow and sediment regimes.

Both federal and state data bases contain dam inventories. The National Inventory of Dams, which includes some 75,000 dams (U.S. Army Corps of Engineers 1996), may seriously underestimate dam density. Criteria for inclusion in the NID database include: dams > 2 m (6 ft) high with storage > 61,700 m^3 (50 acre-feet), those > 8 m (25 ft) high with storage > 18,500 m^3 (15 acre-feet), and those of any size that pose a significance human risk.

While large dams account for the majority of total water storage, and unquestionably cause great ecological damage, the cumulative effects of small dams may receive insufficient attention. In addition, the true number of dams may greatly exceed the number accounted for in the federal database. State databases thus provide a more thorough evaluation of the extent of dams in the Great Lakes Basin.

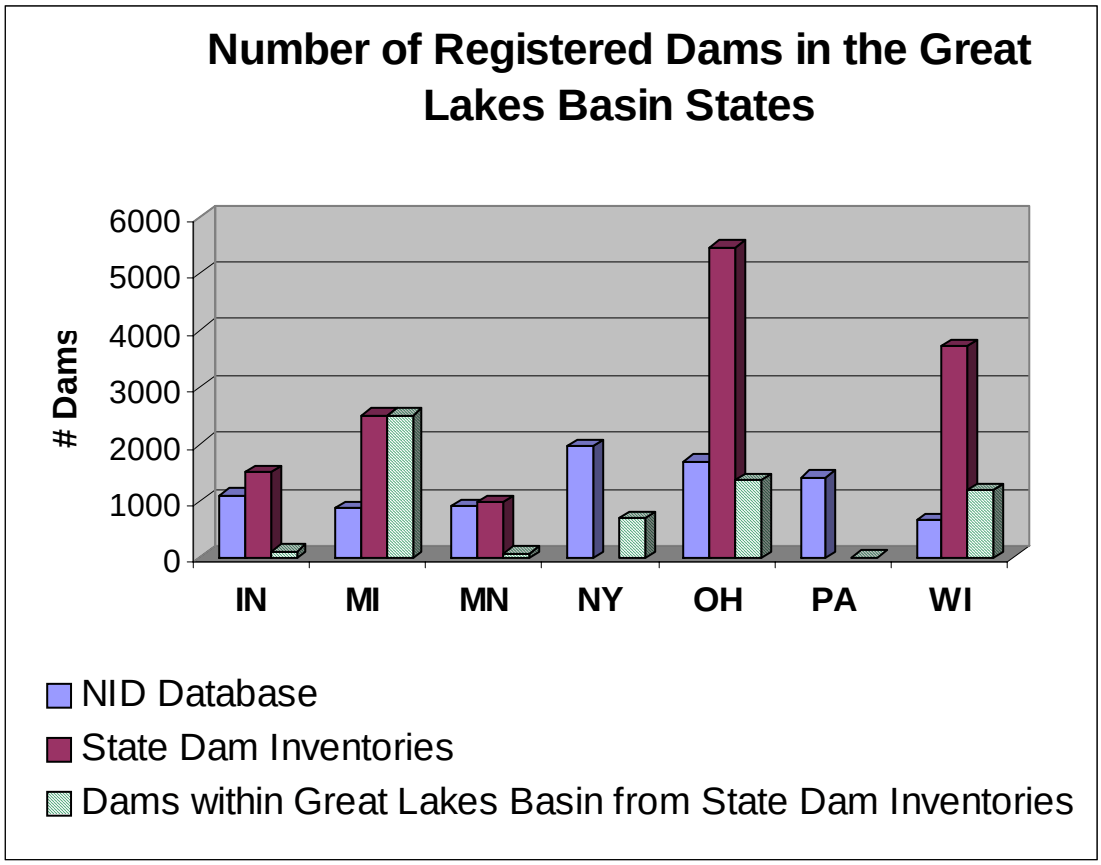
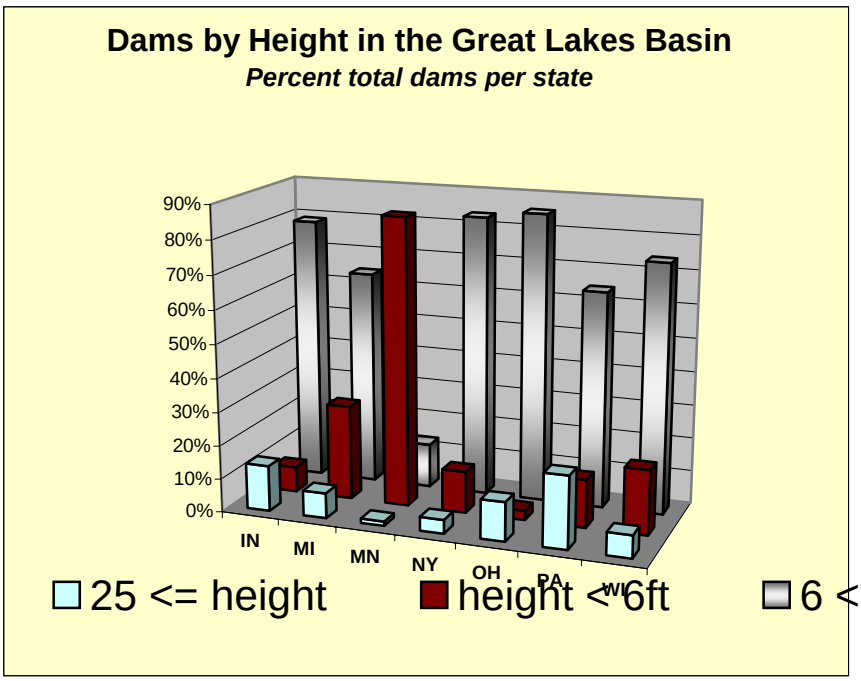


Figure 9. The number of registered dams in the States of the Great Lakes Basin, showing results based on the NID database, State Dam Inventories for each entire state, and the number of dams in state-level databases that are within the boundaries of the Great Lakes Basin.

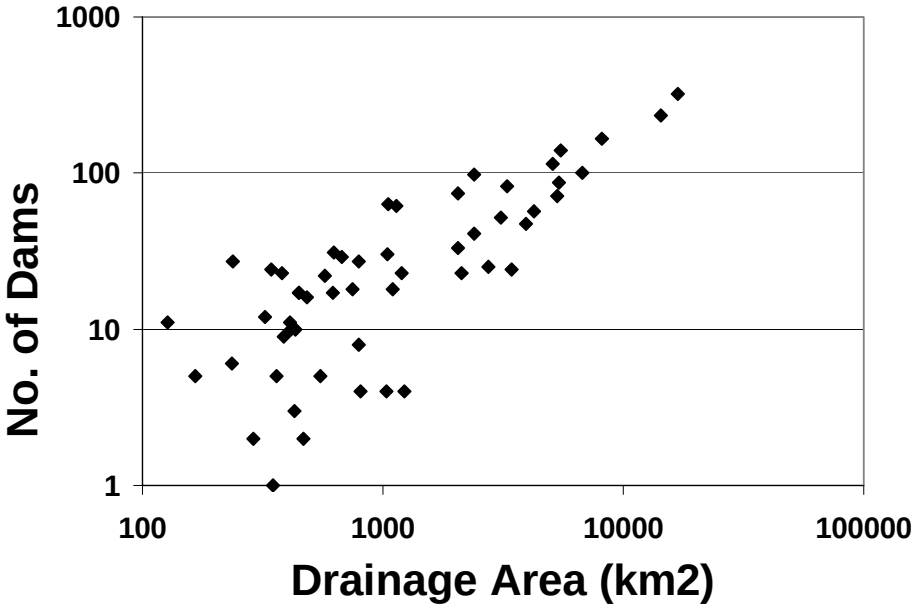
Inventories from State Dam Safety Programs indicate that the "true" number of dams may be twice that recorded in the NID (Figure 9). The number of dams is uncertain for several reasons. Inventories likely are incomplete. Even road crossings and culverts can fragment stream habitat and so a count of dams may under-estimate river fragmentation. On the other hand, many of the additional dams in Michigan are small lake-outlet control devices, which may not be important from the perspective of either flow regulation or habitat fragmentation. As figure 10 demonstrates, the Great Lakes has few dams greater than 25 feet in height, and most dams are between 6 and 25 feet in height. Minnesota is the exception, with approximately 80% of its dams under 6 feet.

Figure 10. The majority of dams in all states except Minnesota are between 6 and 25 feet high. In Minnesota, the majority of dams are less than 6 feet in height. Within the Great Lakes Basin, recreation is the primary purpose for dams, followed by water supply and hydroelectric uses.



Graf (1991) calculated dam density as drainage area per dam for 18 regions of the USA using the NID database. His estimate for the Great Lakes basin was 223 km^2 of drainage basin per dam. We made the same calculation for Michigan, using the State dam database. Our estimate is 63 km^2 per dam. Clearly, river systems are considerably more fragmented by dams than is indicated by prior analyses that focused only on large dams.

Figure 11. Number of dams in each river basin of Michigan in relation to drainage area of that basin.



Unsurprisingly, large river basins contain more dams than small river basins (Figure 11). In Michigan, dam densities < 1 per 100 km2 can be considered low, and densities > 4 per 100 km2 are high. A corollary is that small river basins usually lack dams. Only one river in Michigan with a drainage area < 150 km2 is dammed, and it is a high gradient stream.

Great Lakes Flow Project – A Mapping Tool for Managers and the Public

As an enhancement to this report, resource managers and other audiences are being provided with tools for establishing an overview of their area of interest. The CD accompanying this report contains a customized project for the ArcView 3.x geographic information system, which allows the user to view several collections of archived information related to the Great Lakes.

The tool is focused on the Great Lakes basin and shows the location of historical gaging stations in both the U.S. and Canadian portions of the Great Lakes basin, dam structures from state and national inventories in the U.S., and contact information for local, state and federal agencies and non-governmental organizations active in U.S. Great Lakes watersheds.

With these tools, the user can select a gaging station and request a graph of flows at that station for multiple years of record (Figure 12). The tools also allow the user to select a dam and retrieve profile information for that structure, including age, size, type, regulating agency, etc. And the user can select a watershed and obtain a list of federal, state and local agencies, regional and national non-profit organizations that might be of interest due to regulating authority, information resources, or possible funding or other support programs.

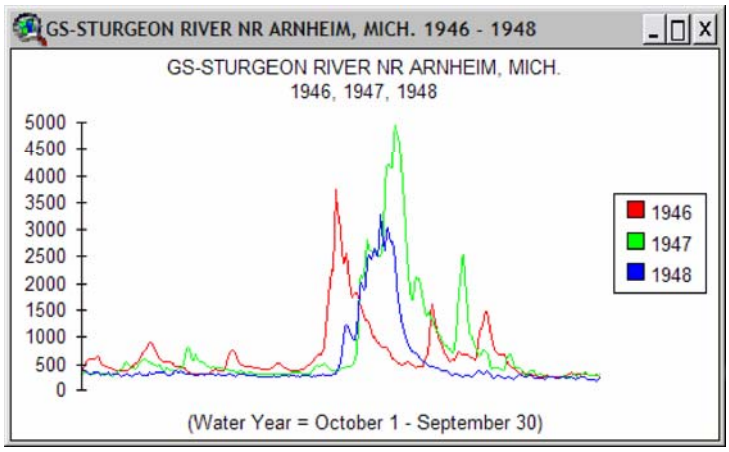


Figure 12. Chart of water flows for three water years at the Sturgeon River gaging station, generated from project data on accompanying report CD.

Geographic information systems are now in widespread use and offer powerful tools to local and regional planners and resource managers. The stream gage and dam data relevant to this project were assembled as ESRI shapefiles or as comma-delimited text and placed on a CD along with a customized data exploration tool developed for one of

the standard GIS software packages, ESRI's ArcView 3.x. Together, they can be used for initial exploration of a local area. The data are non-proprietary and are therefore also available for use in other applications.

The internet has matured to the point where it is now ready to effectively handle geographic information and mapping. A logical next step for this material is to house it on an internet-enabled server for easier updating and instant distribution to a wider audience. From there, users would also be able to take advantage of information integration programs being developed for the U.S. and the Great Lakes region, including programs in individual states, across lake basins and at the federal level, allowing updates to contact information, additional agency links, and the immediate inclusion of additional or more refined data as these become available.

Conclusions and Recommendations

Stream flow is a master variable (Figure 2) that influences lotic systems by regulating important physicochemical characteristics such as channel geomorphology, current velocity, habitat diversity, oxygen concentration, substrate, and water temperature. However, patterns of land and water use by humans have changed the pathways that water moves on the landscape and thereby altered natural flow regimes. These human-induced hydrologic perturbations can lead to novel conditions that no longer sustain healthy ecosystems and native species.

1. Flow regime

The analyses presented in this report support the view that flow regimes can be characterized by hydrologic analysis. Identification of 425 least regulated gages and computation of flow statistics using the Index of Hydrologic Alteration revealed that the majority (70%) of streams of the Great Lakes Basin fall in the perennial runoff category of Poff (1996), a further 22% are stable or super-stable, and the remainder are in snowmelt or snow and rain categories. A map of flow regimes for the streams of Michigan, when superimposed on the State's geology (Figure 6), reveals the strong influence of geology, and especially of slope and permeability, on flow regime. These results support and extend a prior analysis by Richards (1990) that demonstrated strong regional streamflow patterns within the Great lakes basin.

Recommendation: The organizing concept of the flow regime should be integrated into planning and management for water and for healthy waterways throughout the Great Lakes Basin. Given the wide availability of hydrologic data and available techniques for analysis, water management at a location should be informed by knowledge of the flow regime of the stream in question, within the larger context of the surrounding area.

2. Change over time

Components of the flow regime will change in response to variation in climate, water impoundment by dams, water management via stormwater conveyance, and the diverse influences of changing land use (Poff et al. 1997). A comparison of streamflow statistics for 20-year records ending ca.1950 and 1998, for 53 sites in Michigan, documented numerous changes in IHA metrics. Increased runoff and flow magnitude (both high and

low) measures likely are attributable to an overall increase in precipitation, whereas increased predictability of timing may reflect the cumulative impact of dams. The faster rate of rise, well illustrated by the Huron River case study (Figure 8), is best attributed to increases in impervious surface and stormwater conveyance.

Recommendation: A long-term perspective on streamflow is needed to more fully understand human influences. Such analyses should be integrated into planning and management for water and for healthy waterways throughout the Great Lakes Basin. When long-term data are lacking for a particular stream, selection of an analogue stream of similar flow regime characteristics is recommended.

3. Data Analysis and Mapping

The availability of hydrologic data, databases of dams, land cover, geology, and other GIS data layers, combined with software for hydrologic analysis and computer mapping, open the door to new and comprehensive approaches to water management. Using the customized Arc View GIS project included with this report, users, including watershed councils, local governments, and other interested parties, can easily construct hydrographs, retrieve information about dams, and access contact information. This pilot project demonstrates the opportunities for information dissemination regarding Great Lakes data layers, specifically those associated with river flows and dams.

Recommendation: Agencies and funders should invest in the development of easy-to-use data and map products that can be employed by citizen groups and local government to access information on streamflow and dams. The internet has matured to the point where it is now ready to effectively handle geographic information and mapping. A logical next step for this material is to house it on an internet-enabled server for easier updating and instant distribution to a wider audience. From there, users would also be able to take advantage of information integration programs being developed for the U.S. and the Great Lakes region, including programs in individual states, across lake basins and at the federal level, allowing updates to contact information, additional agency links, and the immediate inclusion of additional or more refined data as these become available.

4. Concluding Remarks

There is a growing consensus that "the ecological integrity of river ecosystems depends upon their natural dynamic character" (Poff et al. 1997). Ultimately, re-establishing more natural flow regimes in the rivers of the Great Lakes Basin is a core element of a larger strategy to protect and restore the health of waters of the Great Lakes ecosystem, leading to improvements in the physical environment and restoration of biological health. While dams, water withdrawals, and other direct physical modifications to free-flowing rivers are important, the more subtle influences of altered land use should not be neglected. By identifying the flow regime characteristics of rivers of the Great Lakes Basin, this report contributes to the on-going effort towards improved water management for humans and for ecosystems of the Great Lakes.

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APPENDIX 1

Great Lakes Flow Project – User Guide

Introduction

This tool is a customization of the standard ESRI ArcView 3.x interface. A project file, *gl_flows.apr*, has been created which incorporates several supplemental scripts and a group of default data sets for the Great Lakes region. This tool was specifically designed to give ready access to several collections of archived information related to the Great Lakes:

(1) Historical gaging station records for U.S. and Canadian portions of the Great Lakes basin;
(2) Dam overviews for structures in the U.S. portion of the Great Lakes basin; and
(3) Contact information for local, state and federal agencies and non-governmental organizations active in U.S. Great Lakes watersheds

The background information present includes boundary files showing the five Great Lakes and their connecting water bodies, and the portions of the eight states and two provinces which border on the Great Lakes. A counties/districts layer for the political sub-units within the application's area of reference was also included. These layers have been cropped to less than the full extent of the states/provinces as part of keeping the project's focus on the geographic extent of the Great Lakes basin.

In addition, two sets of spatial reference layers were included for the U.S. portion of the project area. The U.S. roads network drawn from U.S. Bureau of Transportation Statistics data includes road names and classifications, and so could be used to for spatial queries or for cartographic enhancements. And linework from the U.S. National Hydrography Dataset was used to create a schematic of U.S. rivers and major inland water bodies within the Great Lakes basin. Both of these datasets were originally created at scales of 1:100,000 or larger, so they include a great deal of detail. Therefore, they do not display unless the user zooms in significantly. For inland water bodies, the scale denominator must be 1,000,000 or less. For roads, the scale denominator must be 500,000 or less.

ArcView creates a project file (*.apr) to store the settings, data layers and customizations relevant to a particular ArcView session. The original .apr file on the project CD cannot be overwritten. However, if you do a great deal of work in one particular geographic area, it might be worthwhile to store the contents of the project CD on your computer's hard drive and to save this project under a new name after you have worked with it. (Please note that if you save the project under its original name, you will overwrite any default settings. If necessary, these can be restored by copying *gl_flows.apr* from the CD again.)

Project-specific Data

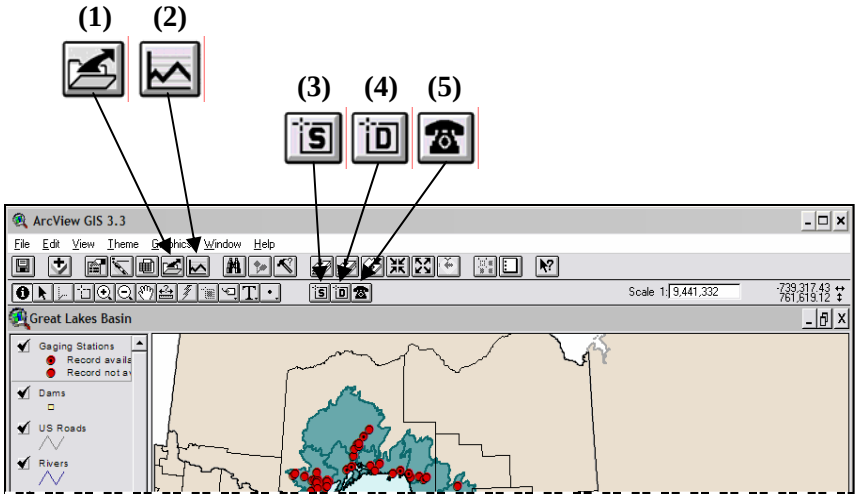
As mentioned above, three sets of newly compiled data were developed specifically for this project: The historical gaging station locations are present as an ESRI shapefile containing 1476 station points. Gaging station identification information can be accessed directly from the shapefile, including the station's name, its location, and the presence or absence of historical recordsets. In some cases, drainage area is also listed, but this information is of unknown quality and its derivation probably varies significantly from station to station. Historical recordsets of gage readings exist for 705 of these locations, and are included as comma-delimited text files separate from the gaging station shapefile. These are stored in the project's \recordsets folder.

U.S. dams within the Great Lakes basin are also present as an ESRI shapefile. There are 4943 dams listed, with dam characteristics stored as part of the shapefile data. A tool built into the ArcView project allows viewing of characteristics for any individual dam, but ArcView analysis tools can also be used directly on this dataset. In addition, the Excel spreadsheets from which the dams layer was compiled are included in a separate \dam_source folder.

Agencies and organizations of interest within a particular watershed are accessible through a phonebook tool built into the ArcView interface. These data are present as dBaseIV-formatted .dbf files in the \phonebook folder and can also be accessed through other software if desired.

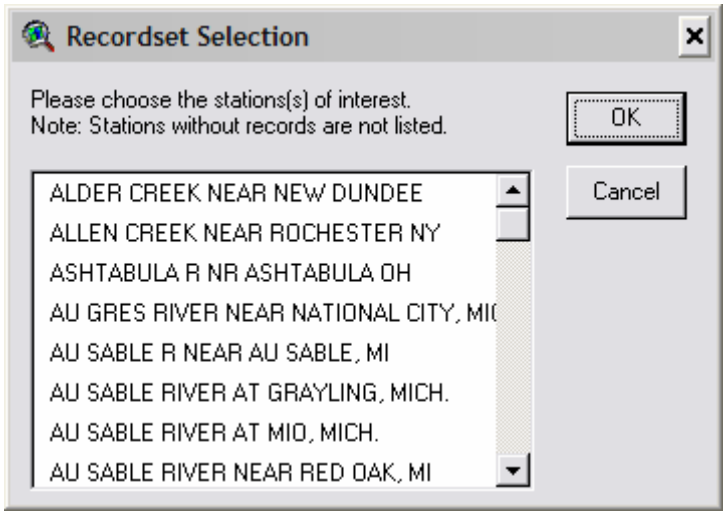
Tools and Functions

As with all ArcView projects, individual data layers can be turned on and off in the View window without losing access to the data. No ArcView functions were disabled in assembling this project. However, the user does need to be aware that the historical recordsets for the gaging stations are independent of the shapefile point layer that is used to depict the gaging station locations. If needed, these data exist as delimited text files in a separate folder (\recordsets). Otherwise, they are best accessed through the tools described below.



(1) Gaging Station Recordset Import:

Clicking on this button opens a "Recordset Selection" window, shown below, which allows the user to select gaging station recordsets without reference to the Gaging Stations shapefile. The user can select one or more gaging stations by name. Note that the control and shift keys are not necessary for multiple selections, and if a station is chosen whose recordset should not be imported, a second click will clear that station from the selected list.

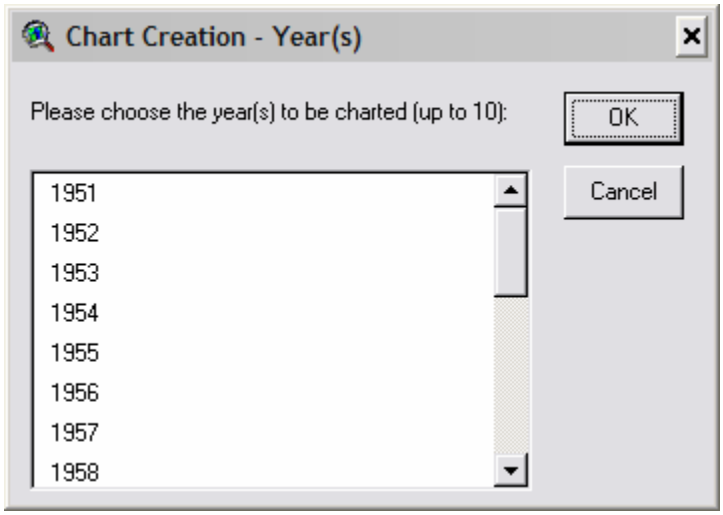


Gaging station recordsets can also be imported by selecting individual station points in the View window. (See the "gaging station selection tool" description below.)

Imported recordsets are added to the Tables list in the ArcView project window, preceded by "GS-" (for Gaging Station). Once imported, these files are accessible until the ArcView session is closed. If the session is saved, preferably under a new project name, the imported recordsets will remain available during future sessions. If not, they will need to be reloaded each time the project is re-opened.

Gaging Station Chart Creation:

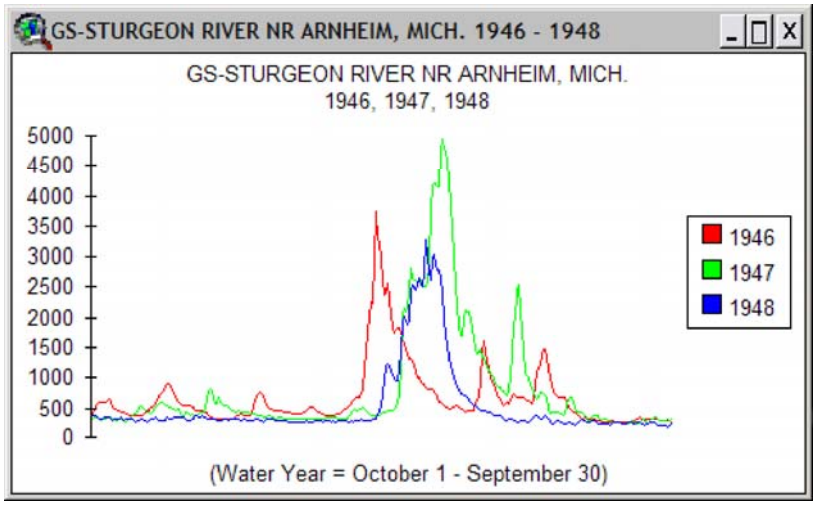
Clicking on this button opens a "Chart Creation" window, shown below, which allows the user to create a chart of water levels at the selected gaging station for multiple years of record. The only recordsets which will be available are those imported using the above import function or the gaging station selection tool described in the next section.



The user will only be able to choose one station at a time for chart creation. If the desired gaging station is not shown in the selection list, please return to the recordset import tool described above, or to the gaging station selection tool (see below) available in the View window, and import the desired recordset into the project.

Once a station has been chosen, the chart creation window opens showing the years of record available for that particular station. Water years run from October 1 to September 30, which is noted on each chart. Up to 10 years of record can be depicted in a single chart, allowing visual comparison of years of interest. Note that the control and shift keys are not necessary for multiple selections, and if a year of record is chosen which should not be shown on the chart, a second click will clear that year from the selected list.

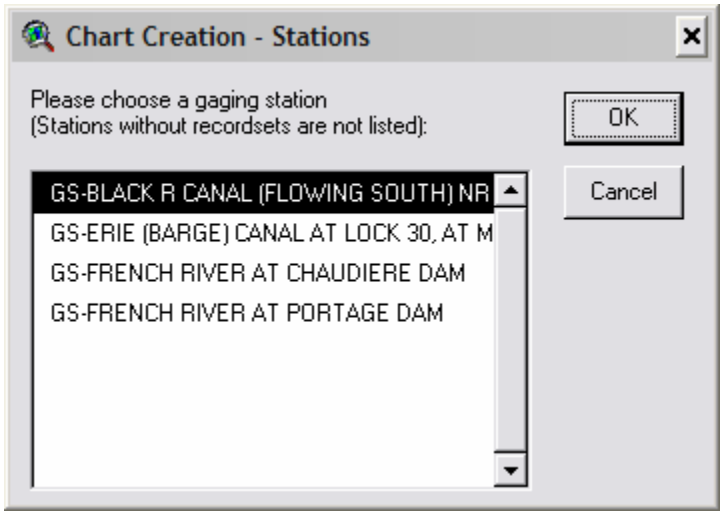
An example chart, taken from the Sturgeon River gaging station near Arnheim, Michigan, is shown below. The station name and years of record chosen for the chart are listed at the top. Along the left side of the display window, the y-axis of the chart shows flow in cubic feet per second (cfs) recorded at that station. Daily flow rates are charted for the entire water year, color coded by year. And the user is reminded that the water year from which these measurements are taken extends from October 1 of the preceding calendar year to September 30 of the calendar year for which the water year is named. Note that the y-axis of each gaging station chart is automatically scaled to the water volume measured at that station. The variations in these scales from station to station can be very large.



Gaging station chart sample – Flow in cubic feet per second measured from Oct. 1 to Sept. 30 for 3 consecutive years (actual measurement dates Oct. 1, 1945 – Sept. 30, 1948).

Gaging Station Selection Tool:

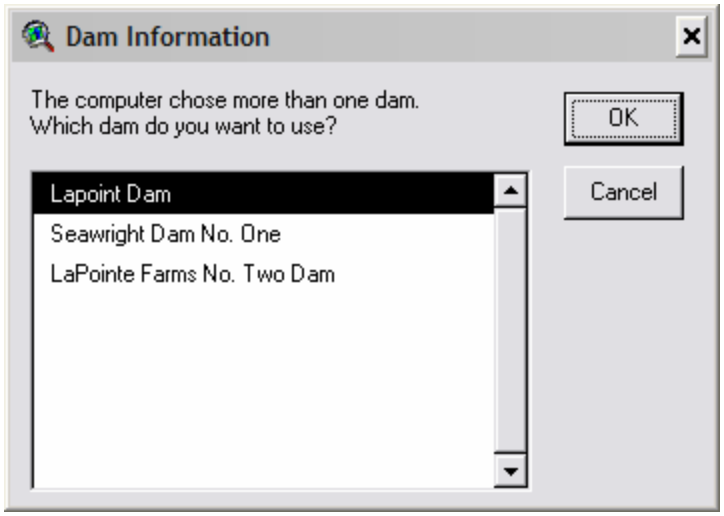
When selected, this tool renders the Gaging Station theme active. The user can then point and click to select individual stations or click and drag to select multiple stations in a single operation. Once the features of interest have been selected, ArcView checks to see which stations have recordsets available and imports the necessary gaging station recordset files. The user is told via a pop-up window how many recordsets were imported, allowing easier assessment of the number of stations with recordsets which are part of a given selection group.



Note that the recordset import process inventories the available recordsets already rendered accessible to ArcView. If a gaging station recordset has already been imported, it will not be added to the list of available data tables a second time. This occasionally makes the import message in the pop-up window confusing, but prevents the list of recordsets available for charting from containing duplicates.

Dam Selection Tool:

When selected, this tool renders the Dams theme active. The user can then point and click to select an individual dam and view the attribute information stored for that structure. The tool only works for one dam at a time, due to the number of details provided for each dam. If the resolution in the view is such that the target of a click is unclear, ArcView will present a pop-up window (see right) from which the user can select one structure by name. Once the feature of interest has been selected, the dam's attributes are displayed in an information window.

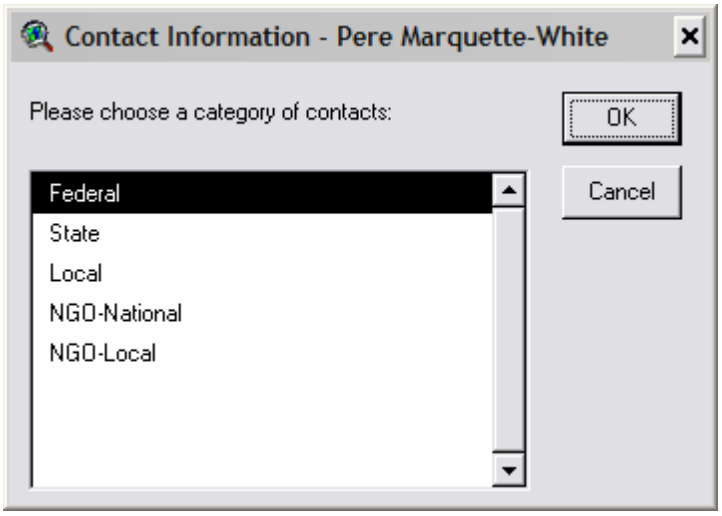


This tool does not import data or otherwise add elements to the ArcView project. The attributes listed are those stored with the points theme that shows the locations of the dams

within the Great Lakes basin. They can thus be accessed using standard ArcView tools as well this customization.

Watershed Phonebook Tool:

When selected, this tool renders the Watersheds theme active. The user is then offered a choice of several "phonebooks" containing contact information for various agencies and organizations active in that watershed. The phonebook choices reflect the various levels of jurisdiction which might be present in the watershed, separated by category to improve accessibility. The categories are:



Federal – U.S. or Canadian federal agencies potentially involved with watershed-related issues. The phonebook listing is for the agency office within whose jurisdiction the watershed is located.

State – State offices involved with watershed-related issues. Where watersheds cross state borders, this phonebook may include listings for similar agencies in multiple states.

Local – County, city and township departments or offices involved with watershed-related issues. Watersheds often incorporate multiple local political units, and this phonebook will frequently contain multiple listings for similar offices in different jurisdictions.

NGO-National – Contact information for national and international non-governmental and non-profit organizations involved with watershed-related issues.

NGO-Local – Contact information for local and regional organizations and institutions involved with watershed-related issues.

The phonebook is displayed in an information window from which entries can be cut and pasted into other documents, used for reference, etc. The phonebooks are stored with the project as a set of data tables separate from the watersheds layer. They can be accessed using ArcView's table functions or through other software as needed.

Great Lakes Flow project – Data Overview

Gaging Stations
Total station points: 1476
Total stations with records: 692

Data fields:
ID .....Gaging station ID number
Lat .....Latitude – decimal degrees
Long .....Longitude – decimal degrees
Station .....Station name
State_Prov .....State or province abbreviation
Drain_sqmi*...Drainage area, square miles
Drain_sqkm*..Drainage area, square kilometers
Hydro_unit* ...(US stations) Hydrologic Unit Code
Start .....First year of record
End .....Last year of record
Years .....Total number of record years
www_link*.....USGS NWIS website link, if available
hasrecords .....Does the station have a record within this project

Dams
Total data points: 4943

Data fields:
State.....Abbreviation of the state within which the dam is located
ID .....Dam ID code
Name .....Dam name
Alt_names* ....Alternate dam names, if available
Lat .....Latitude – decimal degrees
Long .....Longitude – decimal degrees
Water_body*..Water body on which the dam is located
County.....County within which the dam is located
City_Twp* .....Minor Civil Division within which the dam is located
Reg_Agency*.Regulatory agency with jurisdiction over the dam
Owner_Type* Category of dam owner – federal, state, local gov't, private utility, private
Owner_Name* Identity of owner
Hazard* .....Downstream hazard potential if failure or misoperation
Yr_built .....Year original dam construction was completed
Purpose*.....Purpose of dam
Dam_Height...Height from streambed to crest (feet)
Dam_Type*....Type of dam construction
Drain_sqmi.....Drainage area to dam (square miles)
Storage_n .....Total storage at normal retention level (acre-feet)
Storage_m .....Total storage at maximum water surface elevation (acre-feet)
Crest_l .....Length along top of dam at centerline (feet)

Qmax.....Maximum discharge at maximum water surface elevation (cfs)
Kw.....Kilowatts
Pub_Access*..Public access exists? (yes/no)
Fish_Pass*.....Fish passage device exists? (yes/no)

* Note that this characteristic may not have been recorded for all dams.