The Role of Impervious Cover as a Watershed-based Zoning Tool to Protect water Quality in the Christina River Basin of Delaware, Pennsylvania, and Maryland

Gerald J. Kauffman and Tammy Brant
University of Delaware, Institute for Public Administration, Water Resources Agency
DGS Annex, Academy Street
Newark, DE 19716

Gerald J. Kauffman PE is a watershed coordinator with the Water Resources Agency at the University of Delaware, Institute for Public Administration and Tammy Brant is a graduate research assistant in the Marine Policy Program at the University of Delaware, College of Marine Studies, Newark, DE 19716-3501. This manuscript is part of an ongoing watershed-based program in the Christina River Basin of Delaware and Pennsylvania to protect and improve the quality of the streams that provide 75 percent of the water supply for residents of New Castle County, Delaware. The Water Resources Agency provides regional water resources assistance to state and local governments in Delaware and the Delaware Valley in its education, research, and service role at the University of Delaware. Please address comments to Mr. Kauffman at the above address or jerryk@udel.edu.

ABSTRACT

Land and water planners frequently wrestle with the problems of uncontrolled growth and sprawl and their deleterious impacts on water quality. Fortunately, tools such as watershed management and impervious cover thresholds are available to address these problems. Researchers with the Water Resources Agency at the University of Delaware, Institute for Public Administration recommends an approach to protect water supplies and contain sprawl in Delaware through land use planning based on natural hydrogeological boundaries - the watersheds. Impervious cover thresholds can be used to focus growth into watershed zoning districts where development would have the least impact on stream water quality. Since 1991, impervious cover thresholds have been employed within the New Castle County, Delaware zoning code to protect sensitive water resource protection areas during new development. The authors advocate amending the existing code to establish watershed-zoning districts based on percent impervious cover thresholds in the Christina River Basin of Delaware. By employing this concept in county and municipal zoning codes, smart growth can be concentrated in areas with existing infrastructure, while protecting the quantity and quality of Delaware's surface water supplies. Land use zoning based on impervious surface coverage should be considered as an effective, measurable, and scientifically defensible technique to protect stream water quality in the Christina River Basin and other watersheds in the Delaware Valley, the USA, and overseas.

KEYWORDS

Watersheds, basins, impervious cover, zoning.

Copyright (c) 2000 Water Environment Federation. All Rights Reserved.

INTRODUCTION

Land use and water resources planners frequently wrestle with the problems of uncontrolled growth and sprawl and their deleterious impacts on water quality. Fortunately, tools such as watershed management and impervious cover thresholds are available to address these problems. Researchers with the Water Resources Agency at the University of Delaware, Institute for Public Administration recommends an approach to protect water supplies and contain sprawl in Delaware through land use planning based on natural hydrogeological boundaries - the watersheds. Impervious cover thresholds can be used to focus growth into watershed zoning districts where development would have the least impact on stream water quality. Since 1990, impervious cover thresholds have been employed within the New Castle County, Delaware zoning code to protect sensitive water resource protection areas during new development. The authors advocate amending the existing code to establish watershed-zoning districts based on percent impervious cover thresholds in the Christina River Basin of Delaware. The objective is to protect the streams and watersheds, which provide 75 percent of the drinking water for New Castle County citizens and businesses. By employing this concept in county and municipal zoning codes, smart growth can be concentrated in those areas with existing infrastructure, while protecting the quantity and quality of Delaware's surface water supplies. Land use zoning based on impervious surface coverage should be considered as an effective, measurable, and scientifically defensible technique to protect stream water quality in the Christina River Basin and other watersheds in the Delaware Valley, the USA, and overseas.

This article discusses the following facets of a plan to implement impervious cover thresholds for land and water planning at the watershed level in Delaware:

- Technical Basis for Impervious Cover Thresholds
- Watershed Case Study of the Christina River Basin
- Existing Ordinances as the Foundation for Watershed-wide Impervious Cover Thresholds
- Proposal for Watershed Zoning Districts in the Christina Basin

TECHNICAL BASIS FOR IMPERVIOUS COVER THRESHOLDS

Buildings, roads, sidewalks, and other impervious surfaces have necessary functions in modern society and they define the urban and suburban landscape. However, too many buildings and roads in a particular watershed can have a deleterious effect on water resources and stream water quality. Impervious surfaces alter the natural hydrology, prevent the infiltration of water into the ground, and concentrate the flow of stormwater over the landscape. In undeveloped watersheds stormwater filters down through the soil, replenishing groundwater quantity with water of good quality. Vegetation holds down the soil, slows the flow of stormwater over land, and filters out some pollutants, by both the slowing the flow of the water and trapping some pollutants in the root system. As the imperviousness of a watershed increases, the greater volume of stormwater increases the possibility of flooding and reduces the potential for pollutants to settle out; meaning that more pollution is delivered to drinking water streams and aquifers. Too much paving and hardening of a watershed can reduce infiltration and groundwater levels which in turn can decrease the availability of aquifers, streams and rivers for drinking water supplies.

Research completed nationally and in Delaware over the last ten years shows an increasingly significant correlation between impervious surface coverage and stream water quality and habitat. The Journal of the

Copyright (c) 2000 Water Environment Federation. All Rights Reserved.

American Planning Association explored the use of impervious cover as a measurable environmental indicator and growth management tool in the article titled: "Impervious Surface Coverage, The Emergence of a Key Environmental Indicator" (Arnold and Gibbons, 1996). Research by the Delaware Department of Natural Resources and Environmental Control indicates that biological habitat and macroinvertebrate insect diversity dropped sharply at 19 nontidal streams in the Piedmont Physiographic Province of Delaware when the impervious surface coverage in a watershed exceeded 8 to 15% imperviousness (Maxted and Shaver, 1994). Maxted and Shaver also found that the majority of 53 urban streams in Northern Delaware had poor habitat. A strong negative relationship has been found between biotic integrity and increasing land use and riparian conditions, which begin at 10% imperviousness. (Schueler, 1995). A study in the State of Washington found that channel stability and fish habitat quality deteriorate rapidly after 10% imperviousness (Booth, 1991 as cited in Schueler, 1995). The article "Site Planning for Urban Stream Protection", by the Center for Watershed Protection cites research conducted in many geographic areas has yielded a conclusion that stream degradation occurs at relatively low levels of imperviousness of 10% to 20% (Schueler, 1995). Research done in Maryland found that macroinvertebrate diversity declines above 10% imperviousness (Schueler and Gali, 1992 as cited in Schueler, 1995). In Maryland, the abundance and recruitment of brown trout declines sharply at 10% to 15% imperviousness (Galli 1993). Streams with increasing imperviousness exhibit many of the following conditions: increased flood peaks, lower stream flow during dry weather periods, degradation in stream habitat structure, increased stream bank and channel erosion, fragmentation of riparian forest cover, and a decline in fish habitat quality (Pelley, 1997). Based on the weight of this research in Delaware and elsewhere, streams can be considered stressed in watersheds where the impervious coverage exceeds a threshold of 10% to 15% (Brant 1999).

Impervious surface coverage can be an important and measurable indicator of stream water quality and watershed health. Therefore, it is important to understand the typical percentage impervious surface coverage associated with various urban and suburban land uses. Table 1 illustrates the typical impervious surface coverage for land uses common in Delaware and other states.

Most developed land uses exceed the threshold of 10 to 15% impervious cover which define a healthy watershed or stream system. It may initially appear from this table that dispersed development would be desirable, perhaps lots on one or two acres with scattered commercial areas, as it results in the lowest percentage of impervious surface coverage. However on a regional or watershed level, greater overall water quality protection is achieved through more concentrated development. Under the "sprawl" scenario, development is spread over a much broader area, and additional impervious area, in the form of roads, would be needed to link the dispersed community together. Therefore, the best way to minimize impervious surface on a watershed level is to concentrate or cluster development in existing village centers or high density clusters (Schueler, 1994). A clustered approach will decrease the overall impervious cover, resulting in greater protection for the overall watershed, as a much larger percentage of the watershed will be left in its natural condition, preserving water quality. In addition, such centralized development can be directed away from sensitive areas such as stream banks to minimize the negative impact on water quality. Using a variation of the clustering approach, development with high imperviousness would be directed to the existing urban and suburban watersheds, and low impervious development would be focused in the existing open space watersheds.

Copyright (c) 2000 Water Environment Federation. All Rights Reserved.

Reducing impervious cover and utlilizing these thresholds for watershed management can also save money. Roads and sidewalks and other infrastructure can account for over half the cost of a subdivision (CH2M-Hill 1993). If a 32 feet wide roadway were narrowed to 30 feet, the savings would be up to $100 per linear feet or up to $528,000 per mile (Schueler, 1997). Reducing the imperviousness of new development not only benefits the environmental health of streams and watersheds but it would also result in economic savings by the development community.

THE WATERSHED CASE STUDY OF THE CHRISTINA RIVER BASIN

The relationship between impervious cover and stream habitat and water quality can be demonstrated through the case study of the Christina River Basin in Delaware and Pennsylvania (Bowers, Greig, Kauffman 1998). The Christina Basin is situated in the northeast megalopolis along the Mason Dixon line about mid way between Philadelphia and Baltimore. The Basin occupies 565-square miles and includes four major watersheds: the Brandywine Creek, White Clay Creek, Red Clay Creek, and Christina River (Figure 1). The upper 70% of the Basin are situated in the headwaters in Chester County; Pennsylvania and the lower 30% are near the fall line and tidal areas in Delaware. The watershed is trivided into land uses of similar proportions: 1/3 urban/suburban, 1/3 agriculture, and 1/3 open space/forests. Suburban New Castle County and the Cities of Wilmington and Newark draw water supplies from these watersheds for 400, 000 residents. The waters of the Christina Basin are unique to Delaware as they provide 75% of the drinking water supply for New Castle County and contain the First State's only six trout streams.

The Christina Basin has a deep historic, cultural, and economic heritage. The watershed is known as the site of two Revolutionary War battles at Brandywine and Cooches Bridge and the Brandywine style of Wyeth art. The watershed is commercially diverse with the largest concentration of mushroom growers in the United States and the corporate home of international chemical and credit card companies. It also has some of the most productive public gardens in the world at Longwood and Winterthur and a port at Wilmington that is the busiest nationally for tropical fruit and banana imports. Two major institutions of higher learning, the University of Delaware and West Chester University have their campuses here. Amish and Mennonite farmers increasingly settle the agricultural watersheds of the Christina Basin. Over a half million people live in the Christina Basin watershed near the Cities of Newark and Wilmington, Delaware; and West Chester, Downingtown, Chadds Ford, and Coatesville, Pennsylvania. Due to the pastoral nature of the watershed and proximity to the job centers at Wilmington and Philadelphia, the Christina Basin is undergoing intensifying development pressures.

Due to excessive development (increased imperviousness) in some watersheds and the legacy left from the 100 years since the industrial revolution, the waters of the Christina Basin suffer from the following water quality problems:

- Excessive nutrients like phosphorus that disturb the "fishable" quality of the waters;
- Elevated toxics (zinc) levels from Superfund and hazardous waste sites;
- Higher than desired bacteria levels which negatively affect the "swimmable" quality of streams;
- High sediment loads which carry topsoil into turbid streams;
- Health warnings against the consumption of fish from urban waterways due to high PCB readings.
- Degraded stream habitat due to upstream development and suburbanization.

Copyright (c) 2000 Water Environment Federation. All Rights Reserved.

The University of Delaware, Institute for Public Administration, Water Resources Agency utilized a Geographic Information System (GIS) to compile impervious coverage estimates for 38 subwatersheds in Christina Basin (Bowers, Greig, Kauffman 1998). Impervious surface values were estimated by utilizing a GIS land use coverage combined with the percentages published in Table 1. The impervious surfaces for the 38 subwatersheds in the Christina River Basin range from 2% to 47%. The increased urbanization in the Christina Basin led to an increase in the average impervious surface coverage within the Christina Basin watershed from 9% in 1975 to 16% in 1995.

The Brandywine Creek watershed is largely rural and has an average of 13% impervious surface, while the Red Clay Creek watershed has an average of 15% and the White Clay Creek watershed 18% impervious cover. These averages are all right around the 10% to 15 % threshold, which means that there is a window of opportunity to preserve water quality and possibly restore Christina Basin watershed health. A Christina Basin watershed restoration action strategy would include a series of best management practices such as progressive land use and zoning ordinances which utilize impervious cover thresholds.

EXISTING ORDINANCES AS THE FOUNDATION FOR WATERSHED-BASED IMPERVIOUS COVER THRESHOLDS

Since the early 1990's, two governments in Delaware have administered zoning ordinances which utilize impervious cover thresholds to protect sensitive water resources areas during new development. New Castle County and the City of Newark in Delaware have adopted Water Resource Protection Area (WRPA) ordinances to protect the quantity and quality of ground and surface water supplies.
In New Castle County these WRPA ordinances limit the amount of impervious surface coverage for new development to a maximum of 10% to 20% in Cockeysville limestone aquifer, wellhead, recharge, and reservoir water resource protection areas. A new single family development within the Reservoir WRPA zoning district is limited to a maximum impervious cover of 10% which equates to a gross density of 2 to 3 dwelling per acre. Two of the WRPAs, the Cockeysville Drainage Area and the Hoopes Reservoir watershed, include their respective drainage areas so impervious cover thresholds are already employed to protect at least two watersheds in Delaware. The WRPAs are classified as overlay zoning districts thus ensuring a more rigorous and protective level of review and scrutiny during the land development review process. The WRPAs for New Castle County are delineated using a GIS on a 3-map series that covers the entire county.

The University of Delaware, Water Resources Agency is assisting other municipalities and counties in Delaware with the development of WRPA zoning ordinances to protect water quantity and quality by limiting impervious surfaces in sensitive areas. These existing WRPA ordinances provide the foundation and the precedent for a more protective zoning code to protect entire watersheds using impervious cover techniques.

PROPOSAL FOR WATERSHED ZONING DISTRICTS IN THE CHRISTINA BASIN

Copyright (c) 2000 Water Environment Federation. All Rights Reserved.

While the existing Water Resource Protection Area Ordinances in New Castle County are valuable to protect sensitive recharge areas, floodplains and aquifers; they do not protect the whole watershed. To provide greater protection to streams and waterways, other researchers have recommended establishing impervious cover thresholds for new development on a watershed by watershed basis.

An article published by the Center for Watershed Protection divided urban land uses into three categories based on impervious coverage (Schueler, 1996). In watersheds with a low pollutant potential of less than 10% impervious coverage, the goal is to protect water quality with an emphasis on preservation and protection of open, natural space. In watersheds with a medium pollutant potential of 10 to 20% impervious cover, the goal is to limit degradation of water quality with zoning techniques and best management practices. And in areas of high pollutant potential exceeding 20% impervious, redevelopment should be encouraged

Building on this watershed management philosophy, we are advocating the use of impervious surface coverage as a measurable indicator to guide development in the sensitive watersheds of the Christina River Basin of Delaware. Municipal and county comprehensive plans should establish planning districts based on natural watershed boundaries. The watershed zoning districts in the Christina Basin are then prioritized as either "preservation" or "restoration" areas.
Preservation watershed zoning districts would be designed to protect streams of existing good water quality and have the following characteristics:

- Relatively high percentages (over 30 percent) of wooded land and open space
- Relatively low percentages of urban/suburban land uses with low amounts of impervious cover (less than 15 %).
- Relatively few contaminant sources such as hazardous waste sites and wastewater discharges.
- Relatively good water quality, which supports drinking water, recreation, and habitat, uses.

Restoration watershed zoning districts would be designed to restore poor stream water quality and have the following characteristics:

- Lower percentages (less than 30 percent) of wooded land
- Higher percentages of urban suburban land and impervious cover (more than 15%)
- High densities of contaminant sources such as wastewater discharges and hazardous waste sites
- Relatively poor water quality which is impaired for drinking water, recreation, and habitat uses.

The New Castle County and the municipal governments are planning to adopt zoning ordinances, which establish maximum percent impervious thresholds in the watershed planning districts. Using this concept, urban growth and redevelopment would be concentrated and focused in the already developed watersheds where the impervious surface coverage exceeds 40%. Suburban zoning would be applied in the watersheds with 16% to 40% impervious coverage. The principle in these "brownfields" urban and suburban watersheds is to enact zoning that encourages retrofitting to restore water quality. Open space acquisition and conservation zoning would be applied within the relatively undeveloped watersheds where the impervious surface coverage is below 15%. These "green" open space watersheds would have low intensity zoning designed to protect the existing good water quality.

Copyright (c) 2000 Water Environment Federation. All Rights Reserved.

Table 2 summarizes the recommended watershed zoning districts and impervious coverage thresholds that could be employed in the Christina River Basin using these techniques. Watershed-based zoning districts are proposed in the Christina Basin because the watershed: (1) contains the only four drinking water supply streams in Delaware, (2) is the home of the only six trout streams in Delaware, and (3) is the home of 400,000 people which is 60% of the State's population. The amended zoning ordinance would declare that:

"The applicant shall record impervious cover calculations of rooftop and pavement area on the development plans. New development within the Preservation Watershed Districts shall not exceed 15% impervious cover per parcel. New development in Restoration Watershed Zoning Districts shall not exceed 50 percent impervious cover per parcel. The impervious cover of any new development within the Delaware portion of the Christina basin shall not exceed the specifications in Table 2. The impervious cover threshold may be increased up to 5% for a particular site provided the applicant applies for stormwater credits based on recommended best management practices".

According to the watershed zoning district approach, new development would be permitted in the watersheds zoned for open space preservation provided the gross impervious coverage at build out does not exceed 10 to 15% (depending on the individual specifications in the table). State, county, and local open space funding in these less developed watersheds would be prioritized to acquire and protect the remaining undeveloped lands. Suburban growth would be directed toward the watersheds with an existing impervious coverage of 16 to 40% provided the rooftop and pavement area of the development does not exceed this threshold. And in the watershed planning districts which exceed 40% impervious cover, incentives are provided to focus redevelopment and stormwater retrofitting along the urban waterways. A GIS data base is used to track the gross impervious cover amounts based on accumulations in developed land uses in a particular watershed-planning district. As the gross impervious cover of a watershed reached the threshold, growth would be directed toward other watersheds, which could accommodate this development.

To encourage compliance, the ordinance would provide guidance on the following techniques that can be used to minimize impervious cover in new and retrofitted developments:

- Narrower residential road cross-sections and road shoulders
- Shorter road lengths
- Smaller turn arounds and cul-de- sac radii
- Permeable paving for spill over parking areas
- Smaller parking demand ratios
- Smaller parking stalls
- Angled One way Parking
- Clustered Subdivisions with Open Space
- Smaller Front Yard Setbacks
- Shared Parking and Driveways
- Narrower Sidewalks

T0 provide flexible development options, the amended ordinance contains stormwater credits which permit the impervious cover thresholds to be increased at no more than 5 percent for successful incorporation of the following techniques:

Copyright (c) 2000 Water Environment Federation. All Rights Reserved.

- Disconnection of rooftop runoff to splash onto lawns or infiltrate into the groundwater table.
- Reforestation of disturbed areas along riparian stream corridors.
- Removal of impervious surfaces from onsite or from other watersheds.
- Acquisition and protection of open space offsite through conservation easement.

AN EXAMPLE

For instance a new 100 acre residential development is considered in the Brandywine Creek above Wilmington subwatershed where the existing impervious cover is 13%. According to Table 2, the allowable impervious cover of the new development would be limited to 15 %. These guidelines provide several options for the subdivision applicant. The applicant could propose 1/3 acre lots (at 30% impervious) on 50 acres leaving 50 acres in open space for a gross imperviousness for the 100 acre parcel of 15 %. Or the applicant could propose 1/4 acre lots (at 38% impervious) on 40 acres leaving 60 acres in open space for a gross impervious of 15 percent. If the applicant chooses to utilize credits of down spout disconnection, reforestation, and or offsite open space conservation; the allowable impervious cover could be increased to 20% maximum. The zoning code already protects environmental features such as wetlands, floodplains, steep slopes, and forested areas from development so the lot yield estimated for these two examples could be lower depending on the site. The use of the impervious cover threshold provides criteria to protect water quality and quantity yet allows flexibility in site design.

IN SUMMARY

Watershed zoning based on impervious coverage thresholds should be considered as a measurable and scientifically defensible technique to plan for smart growth and protect stream water quantity and quality in the Christina River Basin and the other watersheds in Delaware and the Delaware Valley. Watersheds provide the natural boundaries to guide the land planning decisions that affect stream water quality; after all, watersheds know no political boundaries. The wealth of literature points to a scientific link between the amount of impervious cover and the health of streams and waterways. Watershed management and impervious cover thresholds are tools available to assist the planner with wise land use decisions to protect water supplies. By employing these concepts in the county and municipal zoning codes, growth can be concentrated in those areas with existing development and infrastructure away from the undeveloped watersheds to protect drinking water supplies. Proposals are underway to modify the New Castle County Unified Development Code to incorporate this watershed based on impervious cover thresholds in the Christina Basin of Delaware. These tools are available to assist the planner with wise land use decisions to protect water supplies.

Copyright (c) 2000 Water Environment Federation. All Rights Reserved.

Table 1. Typical Percent Impervious Coverage of Land Uses in Delaware

Land Use	% Impervious Cover
Commercial and business district	85%
Industrial	72%
Residential district with 1/8 acre or less lot size (town houses)	65%
¼ acre lot size	38%
1/3 acre lot size	30%
½ acre lot size	25%
1 acre lot size	20%
2 acre lot size	12%

Table 2. Recommended Watershed Zoning Districts in the Christina River Basin

Watershed Planning District	Area (sq. mi.)	Existing % Impervious Cover (1995)	Maximum Impervious Cover Threshold	Zoning Approach
Brandywine Creek above Wilmington	27	13 %	15 %	Open Space
Brandywine Creek through Wilmington	6	49 %	55 %	Urban
Red Clay Creek above Wooddale	12	12 %	15 %	Open Space
Red Clay Creek below Wooddale	7	32 %	35 %	Suburban
Mill Creek	13	27 %	30 %	Suburban
Pike Creek	7	26 %	30 %	Suburban
Middle Run	4	9 %	10 %	Open Space
White Clay Creek above Newark	10	9 %	10 %	Open Space
White Clay Creek below Newark	15	41 %	45 %	Suburban
Upper Christina River above Cooches Bridge	21	21 %	25 %	Suburban
Tidal Christina River below Smalley's Pond	22	36 %	40 %	Urban
Muddy Run	9	15 %	20 %	Suburban
Belltown Run	6	24 %	30 %	Suburban
Little Mill Creek	9	37%	45 %	Urban

Copyright (c) 2000 Water Environment Federation. All Rights Reserved.

REFERENCES

Arnold, Chester L. Jr., and C. James Gibbons. 1996. Impervious Surface Coverage: The Emergence of a Key Environmental Indicator. *Journal of the American Planning Association* 62, 2: 243-258.

Bowers, J., Greig, D. and Kauffman, G. 1998. Phase I and II Report. *Christina Basin Water Quality Management Strategy.* p. 4-10.

Bowers, J., Greig, D. and Kauffman, G. 1999. Phase III Report. *Christina Basin Water Quality Management Strategy.* p. 1-1.

Brant, T. R. 1999. Community Perceptions of Water Quality and Management Measures in the Naamans Creek Watershed. *Masters Thesis for the Degree of Master of Marine Policy. 146 pp.*

CH2M-Hill, 1993. Costs of Providing Government Services to Alternative Residential Patterns. *Committee on Population Growth and Development*. USEPA Chesapeake Bay Program. Annapolis, MD. 168 pp.

Galli, J. 1994. Department of Environmental Programs, Metropolitan Washington Council of Governments. As reported in: The Importance of Imperviousness. *Watershed Protection Techniques* 1, 3: 1998.

Schueler, Thomas. 1996. Crafting Better Urban Watershed Protection Plans. *Watershed Protection Techniques.* 2, 2: p. 329.

Schueler, Thomas. 1994. The Importance of Imperviousness. *Watershed Protection Techniques*. 1, 3: p.100.

Schueler, Thomas. 1995. *Site Planning for Urban Stream Protection.* Metropolitan Washington Council of Governments: Washington D.C.

Schueler, Thomas. 1997. The Economics of Watershed Protection. *Watershed Protection Techniques* 2, 4: 469-481.

Shaver, E. J., and Maxted, J. R. 1995, *The Use of Impervious Cover to Predict the Ecological Condition of Wadable Nontidal Streams in Delaware.* 7 pp.

Shaver, E. J., and Maxted, J. R. 1996, Technical Note 72 Habitat and Biological Monitoring Reveals Headwater Stream Impairment in Delaware's Piedmont. *Watershed Protection Techniques,* 2, 2: 358-360.

U.S. Department of Agriculture, Soil Conservation Service. 1986. *Technical Release 55.* P.2-5.

Copyright (c) 2000 Water Environment Federation. All Rights Reserved.

Figure 1. Base Map of the Christina Basin

Copyright (c) 2000 Water Environment Federation. All Rights Reserved.