USING MULTIPLE REGRESSION TO QUANTIFY THE EFFECT OF LAND USE ON SURFACE-WATER QUALITY AND AQUATIC COMMUNITIES IN THE NEW JERSEY PINELANDS

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USING MULTIPLE REGRESSION TO QUANTIFY THE EFFECT OF LAND USE ON SURFACE-WATER QUALITY AND AQUATIC COMMUNITIES IN THE NEW JERSEY PINELANDS

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Introduction

Previous Pinelands Commission studies have shown that land-use related watershed disturbance have a substantial effect on the natural water chemistry and biology of Pinelands streams (Zampella 1994, Dow and Zampella 2000, Zampella et al. 2001). Using multiple regression and water-quality data collected at 25 Mullica River basin stream sites (Figure 1), Zampella et al. (2001) related water quality to the percentage of upland agriculture, wetland agriculture, and developed land in the stream basins (Tables 1 and 2, Figure 2). The three altered land uses were included in the models based on the assumption that associated land-use practices, such as wastewater disposal and liming and fertilizing lawns and farmland, are potential sources of pollution. However, spatial and temporal differences in watershed disturbance and mitigating factors, such as wetlands, can also affect land-use/water-quality relationships. The size and position of wetlands in a drainage system can influence water quality (Brinson 1993), and the land use nearest a monitoring station rather than the aggregate land use over an entire watershed may govern water-quality/land-use relationships (Robinson et al. 1996). Land-use/aquatic-community relationships may also be influenced by the proximity of disturbance (Zampella and Laidig 1997, Zampella and Bunnell 1998).

In this study, we used a geographic information system (GIS) and multiple regression to relate water quality at 25 Mullica River basin stream sites to both the extent and position of all the major land uses in the associated basins. We addressed two primary questions. First, does the position of a land use within a watershed influence the relationship between land use and water quality or land use and aquatic-community composition? Second, do temporal factors influence the relationship between land use and water quality? To assess temporal effects on water quality, we analyzed land-use data from two different time periods (1986 and 1995). We also investigated the effects of using land-use data from different sources and analyzing median versus flow-weighted water-quality data on the relationships between land use and water quality.

Pinelands Surface-water Quality

Studies describing the relationship between land use and Pinelands water quality were summarized by Zampella et al. (2001). In the Pinelands, streams draining forested watersheds are typically acidic and nutrient-poor (Morgan and Good 1988, Zampella 1994). In contrast, streams draining upland agriculture and developed lands display elevated pH and dissolved-solid concentrations (Morgan and Good 1988, Watt and Johnson 1992, Zampella 1994, Johnson and Watt 1996). Invasion of the region's aquatic and wetland plant communities by nonnative species and the loss of native species are among the biological consequences of water-quality degradation (Morgan and Philipp 1986, Ehrenfeld and Schneider 1991, Patrick 1996, Zampella and Laidig 1997). Furthermore, the acid waters that characterize streams in forested watersheds may prevent the invasion of native fish (Hastings 1979, 1984, Graham and Hastings 1984, Gonzalez and Dunson 1987, Graham 1993, Zampella and Bunnell 1998) and amphibian communities (Gosner and Black 1957, Freda and Dunson 1986, Bunnell and Zampella 1999) by nonnative species. Water-quality conditions in the Mullica River basin are clearly related to watershed conditions (Figure 2). Specific conductance, pH, and dissolved solids increase along a watershed-disturbance gradient characterized by increasing developed-land and upland-agriculture cover.

Unlike most freshwater systems, weathering of carbonate rock is not a major source of calcium and magnesium in Pinelands streams (Morgan and Good 1988). Yuretich et al. (1981) attributed elevated calcium and magnesium levels in the Mullica River and the Batsto River to possible deep ground-water contributions. Morgan and Good (1988), who more accurately characterized the extent of agricultural and developed land in the headwaters of these two streams, associated the elevated levels of calcium and magnesium with land-use related watershed disturbance. The same pattern has been observed along a wide range of Pinelands watershed conditions (Zampella 1994). Liming is one potential source of these two base cations (Johnson and Watt 1996).

Marine aerosols are a source of sodium and chloride in both disturbed and undisturbed Pinelands streams (Morgan and Good 1988, Yuretich et al. 1981), but the increase in chloride along the Mullica River basin watershed-disturbance gradient (Figure 2) probably reflects land-use patterns. Hay and Campbell (1990) and Robinson et al. (1996) reported a state-wide increase in chloride in New Jersey streams, including several Mullica River sites, from 1976 through 1986. Trends in concentrations of both sodium and chloride were associated with application rates of road-deicing salts (Robinson et al. 1996).

In the Pinelands, elevated phosphorus and ammonia levels have usually been associated with direct sewage discharges (Fusillo 1981, Schornick and Ram 1978, Zampella 1994). The low ammonia levels observed across the nonpoint-source Mullica River basin land-use disturbance gradient (Figure 2) are consistent with Morgan and Good's (1988) conclusion that watershed disturbance has no effect on this nutrient. Carter (1998) estimated nonpoint-source phosphorus and nitrogen loads for five New Jersey Coastal Plain drainage basins, including the Mullica River basin. With the exception of the Mullica River basin, urban land use was the most significant contributor to nonpoint nitrogen and phosphorus loads. For the Mullica River basin, Carter's (1998) modeling exercise indicated that agricultural lands were a significant source of these two nutrients. Howes and Teal (1995) reported that a 15 ha cranberry bog in Massachusetts was a net source of inorganic nitrogen and phosphorus to an outflowing stream. Ammonia accounted for most of the dissolved inorganic nitrogen exported from the bogs. Concentrations of ammonia and acid-leachable phosphate in outflowing waters were about four times the inflowing concentrations.

Nonpoint sources of nitrites and nitrates include fertilizers and septic tanks. Stackelberg et al. (2000) reported that nitrate concentrations in water samples drawn from shallow Kirkwood-Cohansey monitoring wells in undeveloped areas were less than 1.0 mg L^{-1} compared to median concentrations of 3.0 mg L^{-1} and 13 mg L^{-1} for urban and agricultural land, respectively. Szabo et al. (1997) also found elevated nitrate concentrations in Kirkwood-Cohansey wells associated with agricultural land.

Specific conductance, which is expressed in microsiemens per centimeter ($\mu S\ cm^{-1}$) at 25°C, is a measure of the ability of water to conduct an electrical current. It is related to the type and concentration of ions present. Calcium, magnesium, sodium, potassium, chloride, and sulfate ions contribute significantly to conductance in most Pinelands waters.

The Pinelands support an acid-water flora and fauna which suggests that undisturbed Pinelands waters have always been acidic (Kaufman et al. 1988, Morgan 1991). Due to acid deposition, current acidity is controlled primarily by sulfate, with naturally occurring dissolved organic carbon playing an important role (Morgan 1991). The inverse relationship between sulfate concentrations and pH suggests that other processes are influencing pH in basins disturbed by developed land and upland agriculture. Elevated pH in degraded streams appears to be related to increases in base cations and alkalinity. Enhanced primary productivity associated with nutrient enrichment may also play a role (Morgan 1985).

Methods

Study Area

The 1474-km^2 Mullica River basin was the focus of our land-use extent and position modeling effort. This major Pinelands watershed lies almost entirely within the Pinelands National Reserve and drains portions of 23 municipalities in Atlantic, Burlington, Camden, and Ocean Counties. The basin, which displays a range of natural and human-dominated landscapes (Figure 3), comprises several major tributaries, including the Nescochague Creek, Sleeper Branch, Upper Mullica River above Sleeper Branch, Batsto River, Wading River (West Branch Wading River), Oswego River (East Branch Wading River), Bass River, Hammonton Creek, and Lower Mullica River tributaries, including Landing Creek (Figure 4). The unconfined Kirkwood-Cohansey aquifer system underlies the entire Mullica River basin (Rhodehamel 1973, Zapecza 1989, Johnson and Watt 1996).

Land-use/Land-cover Data

We prepared 1986 and 1995 land-use/land-cover profiles from digital data obtained from the New Jersey Department of Environmental Protection (NJDEP, 1995/97 Land Use/Land Cover Update 2001). The 1986 and 1995 NJDEP integrated terrain unit map (ITUM) data combine land-use mapping compiled using 1986 and 1995/1997 aerial photography, the 1986 freshwater-wetlands maps created through the New Jersey Freshwater Wetlands Mapping Program, and a hydrology coverage. Land uses were classified using a modified Anderson et al. (1976) system. Wetlands were classified according to Cowardin et al. (1979). The NJDEP-ITUM data set describes land-use/land-cover using both the general Anderson Level I classification and various subclasses. The general classes include urban (developed land), agriculture (upland agriculture), barren land, forest, wetlands, and water (Table 3).

We also used satellite-derived Landsat Thematic Mapper (TM) land-cover data developed at the Rutgers University Center for Remote Sensing and Spatial Analysis (Lathrop 2000). The TM image is a mosaic of 30 x 30 m pixels, or blocks, each with a color signature that corresponds to the biophysical material on the Earth's surface. A combination of digital-image analysis techniques were used to classify land cover on the 1995 TM image. The classification was then refined using other digital data sets, including the 1986 ITUM land-use data. Because the TM land-cover map was produced prior to the release of the 1995 ITUM land-use data, land use was updated to 1995 conditions on the TM map using 1995 color infrared digital orthophoto quarterquads. The TM classification scheme (Table 4) follows that for the Coastal Change Analysis Program (C-CAP, Dobson et al. 1995). The general land-cover classes include developed land, cultivated land (upland agriculture), vines and bushes (wetland agriculture), grassland, woody land, and barren land (upland forest), and various wetland types (wetlands). Throughout this report, we use a revised land-use/land cover terminology to describe the ITUM and TM land-cover/land-use classes (Tables 3 and 4) and refer to both the ITUM land-use/land-cover data and TM land-cover data as land-use data.

Establishing Distance Weighted Land-use Variables

Determining distances. We used GIS software and a United States Geological Survey (USGS) Digital Elevation Model (DEM) to determine surface-water flow-path direction and flow-path distance to selected Mullica River basin surface-water quality, stream-vegetation, and stream-fish monitoring sites. DEM data were processed by applying techniques that were described by Jenson and Dominique (1988) and incorporated into the GRID module of ArcInfo 8.x software (ESRI, Inc., Redlands, CA, 1982-2000). The DEM consisted of individual 1:24,000 scale, 7.5 minute quadrangles composed of 30 x 30-m grid cells or pixels. Each pixel contained a terrain-elevation value. We tiled the individual DEM quadrangles for the Mullica River basin into a seamless mosaic using ArcInfo software. To help define flow-path direction within the low-relief Coastal Plain topography found throughout the basin, we used stream channels to incise or gully the DEM. Stream channels were identified by rasterizing vector (polygon) hydrography data (NJDEP 1986) to a 30 x 30-m pixel to match the DEM. The DEM pixels associated with the raster streams were then incised by 200 m so that each stream pixel was 200 m lower than its original elevation value. To create a flow-path direction grid for the basin, we used the ArcInfo flow-direction function and removed sinks, or depressions, and assigned a flow-path direction (N, NE, E, SE, S, SW, W, or NW) to each pixel in the DEM.

In ArcView 3.x software (Environmental Systems Research Institute, ESRI, Inc., Redlands, CA, 1988-1992), we rasterized the water-quality monitoring stations to a 30 x 30-m pixel and manually georeferenced the stations to the appropriate stream pixel in the flow-path direction grid. Using the monitoring stations as downstream end points, ArcInfo software and the flow-path direction grid were used to produce drainage basins for each of the stations. A drainage basin included all of the pixels that contributed flow to a particular station.

We converted the raster drainage basins to vector format in ArcInfo and clipped the flow-path direction grid to the drainage-basin lines. For each monitoring station, we used the ArcInfo flow-length function to calculate the distance between the station and each pixel in the associated drainage basin. This process resulted in a flow-path distance grid with each pixel assigned the distance to its corresponding monitoring station. Using ArcView software, we cross-tabulated the flow-path distance data separately with the 1986 and 1995 ITUM land-use data and the 1995 TM data to determine the amount of drainage-basin area within each land-use class and its distance to the monitoring station. These three land-use coverage matrices were summarized individually.

Land-use variables. We established three sets of land-use variables for each of the three land-use coverages (1986 ITUM, 1995 ITUM, 1995 TM). Raw, unweighted drainage-basin percentage values represented one set of variables (DEM variables). To create the set of distance-weighted variables, we summed the inverse of the flow-path distances for all cells within an individual land-use class and divided this value by the sum of all inverse distances for all land-use classes (DWI variables). This transformation gives greater weight to land uses closer to a monitoring station. The second set of distance-weighted variables was defined in a similar manner using the square root of the flow-path distance instead of the distance value (DWS variables). The DWS variable also assigns greater weight to the nearest land uses but the effect is less than that achieved with the DWI variable.

Water-quality Data

Model-development data. For model development, we used water-quality data collected at 25 USGS stream stations between 1995 and 1998 Figure 1. None of the sites were affected by point-source wastewater discharges. Median values were calculated for specific conductance, pH, calcium, magnesium, chloride, sulfate, nitrite plus nitrate-nitrogen, ammonia-nitrogen, and total phosphorus (Table 1). Median ammonia values were below detection limit at all but three stream sites where the median concentration was 0.02 mg L^{-1}. Median total phosphorus concentrations equaled or exceeded the 0.01 mg L^{-1} detection limit at only five of the 25 streams. Flow-weighted values were also calculated. A flow-weighted mean value was calculated for each variable at each site by summing the product of the concentration and flow across all concentration values and then dividing by the sum of the flow values. Concentrations associated with larger flows are weighted more heavily than concentrations associated with smaller flow values.

Model-validation data. Water-quality data collected at 20 other Mullica River basin sites by the Pinelands Commission as part of a cooperative program with county agencies were used to validate the models (Figure 5, Table 2). Field and laboratory methods are described by Dow (1996). Sampling frequency, period of record, and parameters measured varied between sites. All data were collected between November 1992 and October 1994 with no systematic seasonal bias in the sampling frequency. Water-quality parameters that were measured at all sites included pH, specific conductance, nitrite plus nitrate-nitrogen, ammonia-nitrogen, and total phosphorus. Median values for specific conductance, pH, calcium, magnesium, chloride, sulfate, and nitrite plus nitrate-nitrogen are given in Table 2.

Stream-vegetation and stream-fish data

In a previous Pinelands Commission study (Zampella et al. 2001), we used detrended correspondence analysis (DCA) and TWINSPAN to ordinate and classify plant species and sampling sites based on presence/absence data collected at 72 Mullica River basin stream-vegetation survey sites (Table 5). We also ordinated and classified fish species and sampling sites based on presence/absence data collected at 54 stream-fish survey sites in the basin (Table 6). In both ordinations, the major pattern in species composition was represented by the first DCA axis which contrasted sites characterized by native Pinelands species with those characterized by both native and nonnative species (Figures 6 and 7).

We used the DCA axis 1 sites score, which represented an index of overall species composition at a site, for model development and model validation. For each community data set (fish and stream vegetation), we ranked the DCA axis 1 site scores and selected every other site for model development. The remaining sites were used for model validation. Stream vegetation sites with DCA axis 1 site scores greater than 150 were characterized by a high percentage of non-Pinelands plant species (Figure 8). Sites with scores less than 150 supported a high percentage of Pine Barrens District species. With two exceptions, stream-fish survey sites with DCA axis 1 site scores greater than 70 were characterized by high a higher percentage of nonnative species than the remaining sites (Figure 8).

Multiple Regression Models

We used stepwise regression to relate median pH, specific conductance, calcium, magnesium, sulfate, and chloride values to the land-use variables. Separate sets of models were developed for each of the land-use data sets, including unweighted and distance-weighted 1986-ITUM, 1995-ITUM, and 1995-TM data sets. The same general approach was used with the biological data, except that the analysis was limited to the 1995 ITUM data. Flow-weighted water-quality means were also analyzed using the 1995 ITUM data. For the water-quality analyses, ion concentrations were expressed in microequivalents per liter (μe L^{-1}) for model development but the validation results are reported as mg L^{-1}. Models were not developed for nitrite plus nitrate, ammonia, and phosphorus because median concentrations for these variables were below detection limits at most sites (Table 1).

One objective of multiple regression is to analyze the relationship between several independent variables or regressors (e.g., land-use) and a dependent variable (e.g., pH) and explain as much of the variation in the dependent variable as possible (Helsel and Hirsch 1993). This variation is represented by R-square (R^2) values. The resulting model can also be used as a predictive tool. Stepwise regression adds and removes independent variables, evaluating the statistical significance of these variables at each step. This first independent variable and all subsequent independent variables are added to the model if they meet a minimum significance-level criterion. At each step, the stepwise procedure also checks if all independent variables currently in the model meet a second significance criterion. Variables that do not meet this second criterion are removed. We set the entry and exit p values at 0.15 and 0.05 for all water-quality analyses. For the biological-community analysis, we set the entry and exit p value at 0.05. The multiple regression analyses were completed using PC SAS/STAT software (SAS Institute Inc., Cary, North Carolina) and Statistica for Windows (Statsoft Inc., Tulsa, OK, 1994).

Diagnostics. Regression analysis depends on assumptions of normality and linearity regarding the relationship between the independent variables and the dependent variable. Meeting one assumption usually satisfies the other (Zar 1984). The assumption of linearity is met if the residuals (actual values minus predicted values) are distributed evenly above and below zero when plotted against predicted values. This relationship is referred to as homoscedasticity. The opposite condition, heteroscedasticity, exists if the plot reveals increasing variance in the residuals with an increase in predicted values. The variance homoscedasticity criteria was met by log transforming ion and specific conductance values. We did not transform pH values.

Intercorrelation (multicollinearity) among independent variables can adversely influence interpretations regarding the relationships revealed by a regression. We assessed presence of multicollinearity among the independent variables using the variance inflation factor (vif) calculated for each variable. We used a vif of less than 10 as the criterion for indicating that multicollinearity was not adversely affecting model results (Myers 1990).

Comparing multiple regression model results. To identify the "best" model, we compared the different land-use and time-period models using three criteria. We determined which model had the highest R-square value and the lowest PRESS statistic. As a third check on the predictive quality of the different ITUM-based water-quality and biological-community models, we used the Wilcoxon matched-pairs test to determine if there was a significant difference between the residuals produced by the models for the validation-data sets and described which model produced the smallest median residual for the validation-data sets. The R-square value describes the amount of variation in the dependent variable explained by the independent variables. For example, an R-square of 0.90 indicates that 90% of the variability in a dependent variable, such as pH, is explained by the independent variables, such as developed land and upland agriculture. The PRESS statistic provides an estimate of the predictive ability of a model, with lower values indicating better predictive ability (Helsel and Hirsch 1993). The PRESS statistic is based on the data used to develop the regression model. For water-quality variables, we compared the three different ITUM models (DEM, DWI, and DWS) within and between time periods (1986 and 1995). We also compared the 1995 ITUM models to the 1995 ITUM flow-weighted models and the 1995 TM models. For the stream-vegetation and stream-fish variables, we compared the three different 1995 ITUM models (DEM, DWI, and DWS).

The Wilcoxon matched-pairs tests were completed using Statistica for Windows (Statsoft Inc., Tulsa, OK, 1994). Comparison of the 1995 ITUM and 1995 ITUM flow-weighted models was limited to the 21 USGS stations where discharge was measured. Statistical significance was determined after adjusting significance levels for each set of related Wilcoxon matched-pairs tests using the sequential Bonferonni method (Rice 1989).

Water-quality Models

Calcium

ITUM models. The best 1986 ITUM model for calcium was based on DEM land-use values (Table 7a). Analysis of the validation data revealed no significant difference in the absolute residuals (actual minus predicted calcium concentrations) between any of the 1986 models after correcting for multiple comparisons (Table 8a, Figures 9 and 10a). The DEM model produced the smallest median absolute difference between the actual and predicted calcium values (0.19 mg L^{-1}). This model accounted for 91% of the variation in calcium concentrations. Upland forest, wetland, and water were the significant regressors (Table 7a). Upland forest ($R^2 = 0.76$) accounted for the greatest amount of variation in calcium concentrations. R-square values for wetland and water were 0.13 and 0.02, respectively.

The best 1995 ITUM model was also based on DEM land-use values (Table 7a). Analysis of the validation data revealed a significant difference in the absolute residuals between the DEM and DWS models (Table 8a, Figures 9 and 10b). The DEM model produced the smallest median difference between the actual and predicted calcium values (0.21 mg L^{-1}). This model accounted for 92% of the variation in calcium concentrations. Upland forest, wetland, and water were the significant regressors (Table 7a). Upland forest ($R^2 = 0.77$) accounted for the greatest amount of variation in calcium concentrations. R-square values for wetland and water were 0.13 and 0.02, respectively.

The validation analysis revealed no significant difference in the absolute residuals produced by the 1986 and 1995 DEM models (Table 8a, Figures 9 and 10). The R-square and PRESS statistic values for the two models were nearly identical (Table 7a).

The best 1986 ITUM altered-land model was based on DEM land-use values (Table 7a). This model accounted for 86% of the variation in calcium concentrations. Upland agriculture and developed land were the significant regressors (Table 7a). Upland agriculture ($R^2 = 0.68$) accounted for the greatest amount of variation in calcium concentrations. The best 1995 ITUM altered-land model was based on DEM land-use values (Table 7a). This model accounted for 88% of the variation in calcium concentrations. Upland agriculture and developed land were the significant regressors (Table 7a). Upland agriculture ($R^2 = 0.66$) accounted for the greatest amount of variation in calcium concentrations.

1995 ITUM flow-weighted models. The best flow-weighted model was based on DEM land-use values (Table 9). This model accounted for 89% of the variation in calcium concentrations. Upland forest and wetlands were the significant regressors. Based on the R-square values and PRESS statistics, the estimated predictive ability for the ITUM-DEM flow-weighted model was similar to that of the 1995 ITUM-DEM model (Table 9).

1995 TM models. The best TM model was based on DEM land-use values (Table 10). This model accounted for 90% of the variation in calcium concentrations. Upland forest and wetlands were the significant regressors (Table 10). Based on R-square values and PRESS statistics, the predictive ability of the 1995 ITUM-DEM model was slightly better than the TM-DEM model.

Magnesium

ITUM models. Although the R-square value for the 1986 DEM model was the same as that of the 1986 DWS model ($R^2 = 0.88$), the DEM-PRESS statistic was higher (Table 7b). Analysis of the validation data revealed a significant difference in the absolute residuals (actual minus predicted magnesium concentrations) between the 1986 DEM and the 1986 DWI models (Table 8b, Figures 9 and 10a). The DEM model produced the smallest median absolute difference between the actual and predicted magnesium values (0.10 mg L^{-1}). Upland forest ($R^2 = 0.72$) accounted for the greatest amount of variation in magnesium in the DWS model. For the DEM model, upland agriculture ($R^2 = 0.72$) accounted for the greatest amount of variation.

The best 1995 ITUM model was based on DEM land-use values (Table 7b). Analysis of the validation data revealed a significant difference in the absolute residuals between the DEM and DWS models (Table 8b, Figures 9 and 10b). The DEM model produced the smallest median absolute difference between the actual and predicted magnesium values (0.17 mg L^{-1}). This model accounted for 91% of the variation in magnesium concentrations. Upland forest, wetlands, and barren land were the significant regressors (Table 7b). Upland forest ($R^2 = 0.70$) accounted for the greatest amount of variation in magnesium concentrations. R-square values for wetland and barren land were 0.18 and 0.03, respectively.

The R-square and PRESS statistic values indicated that the predictive ability of the 1995 DEM model was greater that of the 1986 DEM model (Table 7b). The validation analysis revealed no significant difference in the absolute residuals produced by the 1986 and 1995 DEM models (Table 8b, Figures 9 and 10) after correcting for multiple comparisons

The initial 1986 DEM model represented an altered-land model. The best 1995 ITUM altered-land model was based on DEM land-use values (Table 7b). This model accounted for 91% of the variation in magnesium concentrations. Upland agriculture, developed land, and barren land were the significant regressors (Table 7b). Upland agriculture ($R^2 = 0.70$) accounted for the greatest amount of variation in magnesium concentrations. R-square values for developed land and barren land were 0.19 and 0.02, respectively.

1995 ITUM flow-weighted models. The DEM flow-weighted model produced the highest R-square value ($R^2 = 0.90$) although the PRESS statistic of the DWS model was lower (Table 9). Upland forest, wetlands, and barren land were the significant regressors in the DEM model. Based on the R-square values and PRESS statistics, the estimated predictive ability for the ITUM-DEM flow-weighted model was similar to that of the 1995 ITUM-DEM model.

1995 TM models. The best TM model was based on DEM land-use values (Table 10). This model accounted for 89% of the variation in magnesium concentrations. Upland agriculture and developed land were the significant regressors (Table 10). Based on R-square values and PRESS statistics, the predictive ability of the 1995 ITUM-DEM model was slightly better than the TM-DEM model.

Chloride

ITUM models. The R-square values for 1986 DEM and 1986 DWS models were the same ($R^2 = 0.88$) but the PRESS statistic of the DWS model was lower (Table 7c). Analysis of the validation data revealed no significant difference in the absolute residuals (actual minus predicted chloride concentrations) between any of the three models (Table 8c, Figures 9 and 10a). The median absolute residuals for the models ranged from 1.2 to 1.4 mg L^{-1}, with the DEM model producing the smallest value. Developed land and upland forest were the significant regressors in the DEM model (Table 7c). Developed land ($R^2 = 0.81$) accounted for the greatest amount of variation in chloride concentrations. The R-square value for upland forest was 0.07.

The best 1995 ITUM model was based on DEM land-use values (Table 7c). Analysis of the validation data revealed no significant difference in the absolute residuals between any of the 1995 models (Table 8c, Figures 9 and 10b). The median absolute residual produced by all three models was the same (1.3 mg L^{-1}). The DEM model accounted for 89% of the variation in chloride concentrations. Developed land and upland forest were the significant regressors, with developed land ($R^2 = 0.83$) explaining a higher percentage of the variation in chloride concentration compared to upland forest ($R^2 = 0.06$).

The validation analysis revealed no significant difference in the absolute residuals produced by the 1986 and 1995 DEM models (Table 8c, Figures 9 and 10). Although the 1995 model had a slightly higher R-square value than the 1986 model, the press statistic of the1986 model was lower (Table 7c).

The best 1986 ITUM altered-land model was based on DEM land-use values (Table 7c). This model accounted for 88% of the variation in chloride concentrations. Developed land and upland agriculture were the significant regressors (Table 7c), with developed land ($R^2 = 0.81$) accounting for the greatest amount of variation in chloride concentrations. The best 1995 ITUM altered-land model was based on DEM land-use values (Table 7c). This model accounted for 88% of the variation in chloride concentrations. Developed land and upland agriculture were the significant regressors (Table 7c), with developed land ($R^2 = 0.83$) accounting for the greatest amount of variation in chloride concentrations.

1995 ITUM flow-weighted models. The best flow-weighted model was based on DEM land-use values (Table 9). This model accounted for 89% of the variation in chloride concentrations. Developed land and upland agriculture were the significant regressors. Although the R-square value for flow-weighted model was higher than that of the 1995 ITUM-DEM model (0.89 vs. 0.86), the latter had a lower PRESS statistic (Table 9).

1995 TM models. The best TM model was based on DEM values (Table 10). This model accounted for 88% of the variation in chloride concentrations. Developed land and upland agriculture were the significant regressors. Although the results obtained for the 1995 ITUM-DEM model were similar to those of the TM-DEM model, the R-square and PRESS statistic for the ITUM model were slightly better.

Sulfate

ITUM models. The best 1986 ITUM model for sulfate was based on DEM land-use values (Table 7d). This model accounted for 54% of the variation in sulfate concentrations. Upland agriculture was the only significant regressor (Table 7d). Analysis of the validation data revealed no significant difference in the absolute residuals (actual minus predicted sulfate concentrations) between the DEM, DWI, and DWS models (Table 8d, Figures 9 and 10a). The DEM and DWS models produced the smallest median absolute differences between the actual and predicted sulfate values (2.4 mg L^{-1}).

Results for the 1995 ITUM models was similar to that of the 1986 models. The best 1995 ITUM model was based on DEM land-use values (Table 7d). This model accounted for 56% of the variation in sulfate concentrations. Upland agriculture was the only significant regressor (Table 7d). Analysis of the validation data revealed no significant difference in the absolute residuals between the three models (Table 8d, Figures 9 and 10b). Median absolute differences between the actual and predicted sulfate values were similar for all three models, ranging from 2.5 to 2.6 mg L^{-1}.

All models represented altered-land models. The validation analysis revealed no significant difference in the absolute residuals produced by the 1986 and 1995 models (Table 8d, Figures 9 and 10). The 1995 models had higher R-square values and lower PRESS statistics compared to their 1986 counterparts (Table 7d).

1995 ITUM flow-weighted models. The DEM flow-weighted model produced the highest R-square value ($R^2 = 0.60$) but the PRESS statistic of the DEM model ($R^2 = 0.56$) was lower (Table 9). The same was true for the two DWS models. Upland forest ($R^2 = 0.48$) and developed land (R^2

= 0.12) were the significant regressors in the DEM flow-weighted model, while upland agriculture was the only significant regressor in the DEM model.

1995 TM models. The best TM model was based on DEM land-use values (Table 10). This model accounted for 51% of the variation in sulfate concentrations. Upland agriculture was the only significant regressor (Table 10). Based on R-square values and PRESS statistics, the predictive ability of the 1995 ITUM-DEM model was better than the TM-DEM model.

Specific Conductance

ITUM models. The best 1986 model was based on the DWI land-use values. The DWI model produced the highest R-square value ($R^2 = 0.83$) and the lowest PRESS statistic (Table 7e). Analysis of the validation data revealed no significant differences in the absolute residuals (actual minus predicted specific conductance) between any of the models (Table 8e, Figures 9 and 10a). The DEM model, with an R-square value of 0.82, produced the lowest median absolute residual (7.4 $\mu S\ cm^{-1}$). Upland forest was the only significant regressor in the DWI model. Developed land ($R^2 = 0.65$) and upland agriculture ($R^2 = 0.18$) were the significant regressors in the DEM model.

The 1995 DEM model produced the highest R-square value ($R^2 = 0.84$) but the PRESS statistic of the 1995 DWI model was the lowest of the three models (Table 7e). Analysis of the validation data revealed no significant differences in the absolute residuals between any of the models (Table 8e, Figures 9 and 10b). The DEM model produced the lowest median absolute residual (7.8 $\mu S\ cm^{-1}$). Upland forest was the only significant regressor in the DWI model ($R^2 = 0.83$). Developed land ($R^2 = 0.68$) and upland agriculture ($R^2 = 0.16$) were the significant regressors in the DEM model.

The validation analysis revealed a significant difference in the absolute residuals produced by the 1986 and 1995 DWI and DWS models, although the actual differences were relatively minor (Table 8e, Figures 9 and 10). The results obtained for the 1986 and 1995 DEM models were not significantly different.

1995 ITUM flow-weighted models. The DWS flow-weighted model produced the highest R-square value ($R^2 = 0.86$) but the PRESS statistic of the DWI model was lower (Table 9). Upland forest was the only significant regressor in the DWI model. Significant regressors in the DWS model were developed land and upland forest. Upland forest and developed land also comprised the flow-weighted DEM model ($R^2 = 0.85$). Within-type (e.g., DEM vs. DEM) comparison of the 1995 ITUM and 1995 ITUM flow-weighted models indicated that, except for the DWI model, the R-square values for the ITUM flow-weighted models were higher than the corresponding 1995 ITUM models. However, the PRESS statistic values for the ITUM models were lower.

1995 TM models. The best TM model was based on the DEM data (Table 10). This model accounted for 83% of the variation in specific conductance. Developed land and upland agriculture were the significant regressors (Table 10). Similar results were obtained using the 1995 ITUM-DEM data (Table 10).

pH

ITUM models. The best 1986 model was based on the DWS land-use variables. The DWS model produced the highest R-square value ($R^2 = 0.89$) and the lowest PRESS statistic (Table 7f). Analysis of the validation data revealed significant differences in the absolute residuals (actual minus predicted pH) between the DEM model and the other two models (Table 8f, Figures 9 and 10a). The DEM model, with an R-square value of 0.85, produced the lowest median absolute residual (0.30 pH units). Developed land and upland agriculture were the significant regressors in both the DEM and DWS models (Table 7f), with developed land accounting for the greatest amount of variation in pH (DEM $R^2 = 0.71$ and DWS $R^2 = 0.73$).

The 1995 DWS model also produced the highest R-square value ($R^2 = 0.90$) and the lowest PRESS statistic (Table 7f). Analysis of the validation data revealed significant differences in the absolute residuals between the DEM model and the DWI and DWS models (Table 8f, Figures 9 and 10b). The DEM model, with an R-square value of 0.87, produced the lowest median absolute residual (0.30 pH units). Developed land and upland agriculture were the significant regressors in both the DEM and DWS models (Table 7f), with developed land accounting for the greatest amount of variation in pH (DEM $R^2 = 0.75$ and DWS $R^2 = 0.76$).

The initial DEM and DWS models for both time periods represented altered-land models. The validation analysis revealed no significant between-period differences in the absolute residuals produced by DEM, DWI, or DWS models (Table 8f, Figures 9 and 10).

1995 ITUM flow-weighted models. The best flow-weighted model was based on the DWS land-use values (Table 9). This model accounted for 90% of the variation in pH. Developed land, upland agriculture land, and water were the significant regressors (Table 9). The R-square value for the flow-weighted DWS model was greater than that of the 1995 ITUM-DWS model, but the PRESS statistic for the latter model was slightly lower.

1995 TM models. The best TM model was based on the DWS land-use values (Table 10). This model accounted for 90% of the variation in pH. Developed land and upland agriculture were the significant regressors (Table 10). These results were similar to those obtained using the 1995 ITUM-DWS data.

Biological Models

Stream-vegetation Models

The 1995 DEM model produced the highest R-square value ($R^2 = 0.68$) and the lowest PRESS statistic (Table 11). Analysis of the validation data revealed no significant differences in the absolute residuals between the three models (Table 12, Figures 11 and 12). The DWI model, with an R-square value of 0.56, produced the lowest median-absolute residual (33 DCA units). Developed land, upland agriculture, and wetland agriculture were the significant regressors in the DEM model (Table 11), with upland agriculture accounting for the greatest amount of variation in DCA scores ($R^2 = 0.57$). Upland agriculture ($R^2 = 0.56$) was the only significant regressor in both the DWI and DWS model.

As previously discussed, stream-vegetation sites with DCA axis 1 site scores greater than 150 were characterized by a high percentage of non-Pinelands plant species. Sites with scores less than 150 supported a high percentage of Pine Barrens District species. The validation results for all three stream-vegetation models demonstrated that land-use can be used to accurately predict DCA site scores associated with altered stream-vegetation community composition (Figure 13). For all three models, the majority of the sites with a predicted score ≥ 150 were among those originally grouped in the non-Pinelands TWINSPAN site class.

Stream-fish Models

The 1995 DWI model produced the highest R-square value ($R^2 = 0.74$) and the lowest PRESS statistic (Table 13). Analysis of the validation data revealed a significant difference in the absolute residuals between the DEM and DWI models (Table 14, Figures 14 and 15). The DEM model, with an R-square value of 0.69, produced the smallest median absolute difference (7.2) between the actual and predicted fish DCA scores. Upland agriculture and developed land were the significant regressors (Table 13). Upland agriculture ($R^2 = 0.56$) accounted for the greatest amount of variation in fish DCA scores. The R-square value for developed land was 0.13.

As previously mentioned, stream-fish survey sites with DCA axis 1 site scores greater than 70 were generally characterized by high non-native species richness. The validation results obtained for all three models demonstrated that land-use can be used to accurately predict DCA site scores associated with non-Pinelands fish assemblages (Figure 16). In all three models, DCA scores for seven validation sites were predicted to be ≥70. Five of the seven sites were among those originally grouped in the non-Pinelands TWINSPAN site class. The two other sites also supported nonnative fish species.

Conclusion

The effect of landscape position on the relationship between land use and water quality varied among the different water-quality parameters. Although the predictive ability of some DWI and DWS models was better than that of the associated DEM models, the differences were subtle. Similar results were found for the biological data. The effect of distance-weighted land-use variables was most pronounced with specific conductance, pH, and fish-community site scores. The lack of major differences among the models reflect the high correlation between the DEM, DWI, and DWS land-use variables. Temporal effects (1986 vs. 1995) were also subtle. The absence of dramatic differences in the results of the 1986 and 1995 water-quality analysis reflects the small changes in land-use transitions between these two periods. The maximum change in altered lands in the model development basins was a 6.6% increase in developed land and 3.5% decrease in upland agriculture. The median change for developed land and upland agriculture was 1.1% and -0.64%, respectively. Incorporating flow into the water-quality analysis produced results similar to those obtained using median water-quality values. The results obtained using two different sources of land use data (ITUM and TM) were also similar.

In several cases, one model for a water-quality variable retained altered lands (upland agriculture or developed lands) while another model for the same water-quality variable removed these land-use variables and retained forest lands (upland forest, wetlands, or water). The removal of developed land and upland agriculture in some models is probably due to closure, that is, the presence of forest land is associated with the absence of developed land or farmland. (Barringer et al. 1990). The inclusion of upland forest and the exclusion of developed land and agricultural land suggests that it is the amount of open space rather that the type of land use (upland agriculture versus development) that matters. The significance of upland forest compared to wetlands in many models reflects the strong negative association between upland forest and both developed land and upland agriculture.

Our analysis demonstrates that land use is a good predictor of Pinelands water-quality conditions. The results obtained using unweighted and distance-weighted land-use data or median and flow-weighted water-quality data were similar. The implication is that water-quality data collected without associated discharge measurements and the more easily obtained unweighted land-use variables are adequate. The analyses revealed that the simplest and most practical approaches represent a extremely effective predictive tools.

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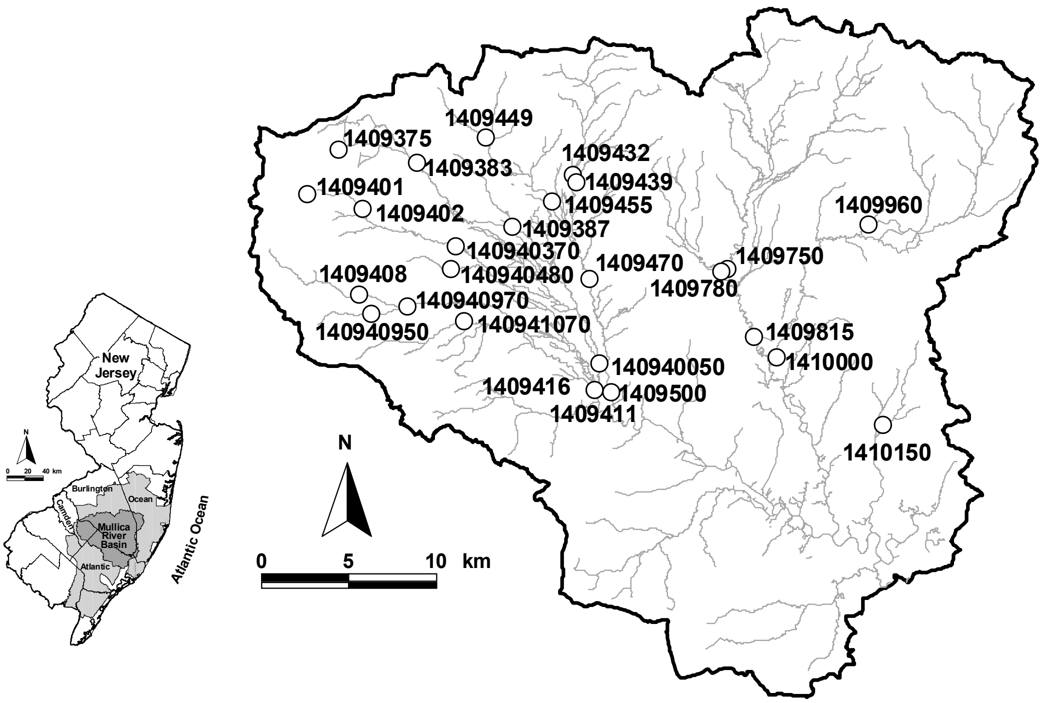

Figure 1. Location of 25 USGS water-quality monitoring sites and station numbers included in regression analyses. Refer to Table 1 for site descriptions.

Table 1. USGS water-quality monitoring stations in the Mullica River Basin (Zampella et al. 2001). Median water-quality values are for a 3-yr period (October 1995 - September 1998) except as noted. All medians except pH and specific conductance (µS cm^{-1}) are mg L^{-1}. Ammonia and Nitrite+Nitrogen are expressed as nitrogen. Refer to Figure 1 for site locations.

		Median Water-quality Values								
Stream Station	Station Number	pH	Specific Conductance	Calcium	Magnesium	Chloride	Sulfate	Ammonia	Nitrite + Nitrate	Total P
Oswego River basin										
Papoose Branch near Sim Place (1)	1409960	4.2	39	0.50	0.30	3.3	3.3	< 0.03	< 0.05	< 0.01
Oswego River at Harrisville (2)	1410000	4.3	51	0.62	0.43	4.6	7.1	< 0.03	0.07	0.01
Wading River basin										
Tulpehocken Creek near Jenkins	1409780	4.6	33	0.42	0.27	2.9	2.7	0.02	< 0.05	< 0.01
Wading River above Tulpehocken Creek	1409750	4.5	41	0.66	0.39	4.3	5.2	< 0.03	< 0.05	0.02
Wading River at Maxwell (1)	1409815	4.4	43	0.57	0.36	4.1	4.8	< 0.03	< 0.05	0.02
Bass River basin										
East Branch Bass River	1410150	4.4	48	0.47	0.51	6.0	3.8	< 0.03	< 0.05	< 0.01
Nescochague Creek basin										
Pump Branch near Waterford Works	1409408	6.5	82	3.1	2.3	13	4.0	< 0.02	1.10	< 0.01
Blue Anchor Brook at Elm	140940950	7.0	73	2.9	1.5	10	5.6	< 0.02	0.11	0.03
Albertson Brook near Elm	140940970	6.4	74	3.1	2.0	11	6.1	< 0.02	0.84	< 0.01
Great Swamp Branch	140941070	6.2	122	8.3	3.8	11	20	0.02	2.25	< 0.01
Nescochague Creek at Pleasant Mills	1409411	5.7	67	3.1	1.8	9.3	8.4	< 0.02	0.32	< 0.01
Sleeper Branch basin										
Hays Mill Creek at Atco	1409401	6.8	104	4.8	2.4	17	6.6	< 0.02	0.58	< 0.01
Hays Mill Creek near Chesilhurst	1409402	6.5	97	3.6	1.8	16	6.5	< 0.02	1.05	< 0.01
Sleeper Branch near Atsion	140940370	5.9	63	2.1	1.2	10	4.7	< 0.02	0.51	< 0.01
Clark Branch near Atsion	140940480	4.6	63	2.6	1.4	7.6	9.3	< 0.02	< 0.05	< 0.01
Mullica River basin										
Mullica River near Atco	1409375	6.8	123	4.9	1.9	22	9.6	< 0.02	0.40	< 0.01
Mullica River at Jackson Road	1409383	4.5	70	1.2	0.62	9.0	3.9	< 0.02	< 0.05	< 0.01
Mullica River at outlet of Atsion Lake	1409387	4.5	51	1.2	0.62	6.2	5.3	< 0.03	0.11	< 0.01
Mullica River at Constable Bridge	140940050	5.0	45	1.2	0.70	6.8	4.3	0.02	0.07	< 0.01
Basto River basin										
Batsto River at Hampton Furnace	1409432	5.2	49	1.7	1.1	5.3	6.0	< 0.02	0.42	< 0.01
Skit Branch at Hampton Furnace	1409439	4.5	31	0.37	0.26	3.0	3.6	< 0.02	< 0.05	< 0.01
Indian Mills Brook (1)	1409449	6.8	100	5.9	2.7	13	11	< 0.03	0.30	0.08
Springers Brook near Hampton Furnace	1409455	6.3	112	6.4	2.9	15	13	< 0.02	0.14	< 0.01
Batsto River at Quaker Bridge	1409470	5.4	50	2.2	1.2	6.5	5.8	< 0.02	0.14	< 0.01
Batsto River at Batsto	1409500	4.8	54	2.0	0.99	6.0	8.0	< 0.03	0.14	< 0.01

(1) Period of record (October 1997 - September 1998) (2) Period of record (October 1995 - September 1996)

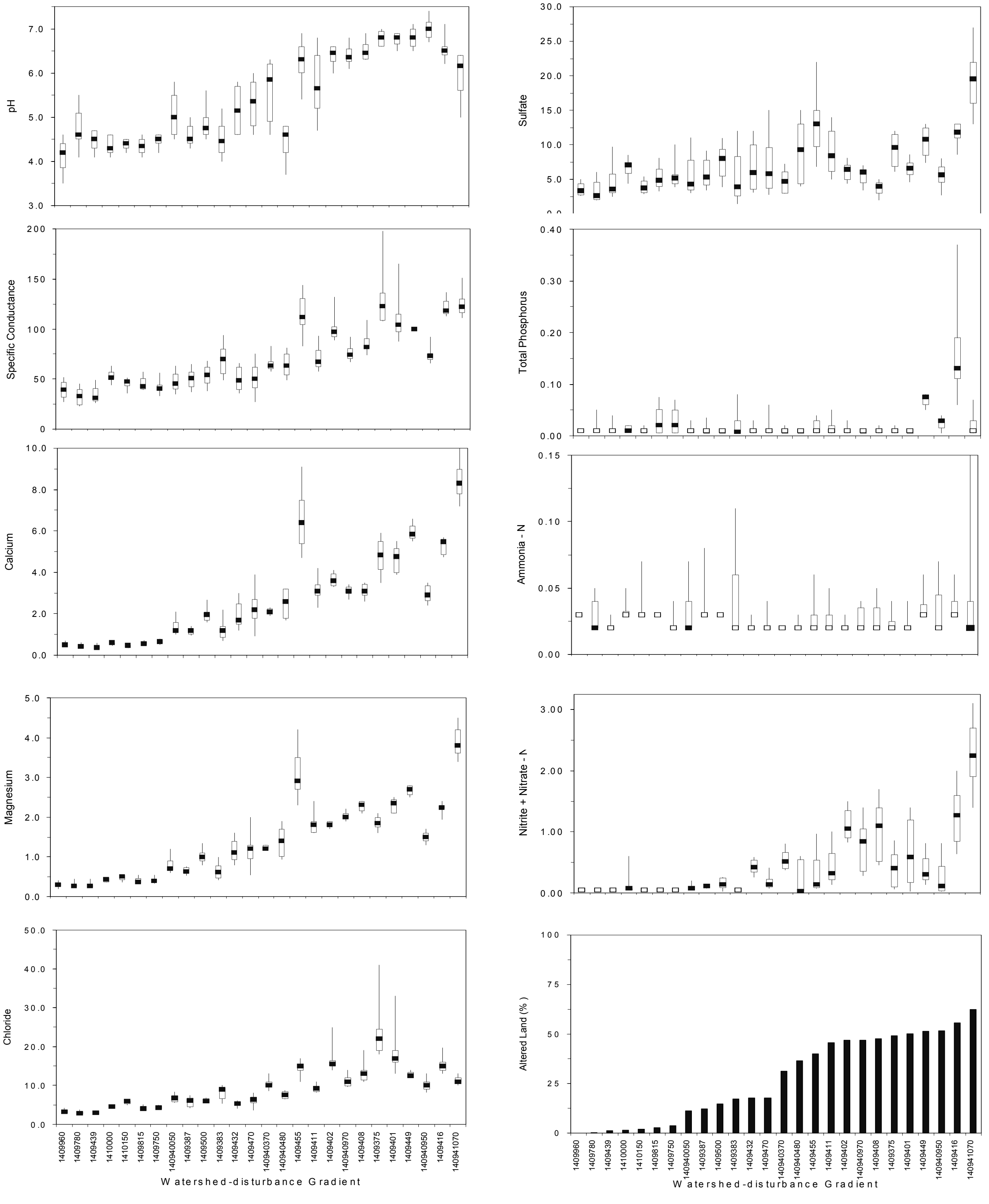

Figure 2. Mullica River Basin surface-water quality gradients. Sites are ordered along the watershed-disturbance gradient by increasing percentage of altered-land cover (developed land and upland agriculture). Water-quality values are medians, quartiles, and 10th and 90th percentiles. Values below detection limit for ammonia - N (0.02 or 0.03 mg L^{-1}), nitrate + nitrite - N (0.05 mg L^{-1}) and total phosphorus (0.01 mg L^{-1}) are shown as open squares. All values except pH and specific conductance (μS cm^{-1}) are in mg L^{-1}. Stream-station names are given in Table 1 (Hammonton Creek No. 1409416 not listed). From Zampella et al. (2001).

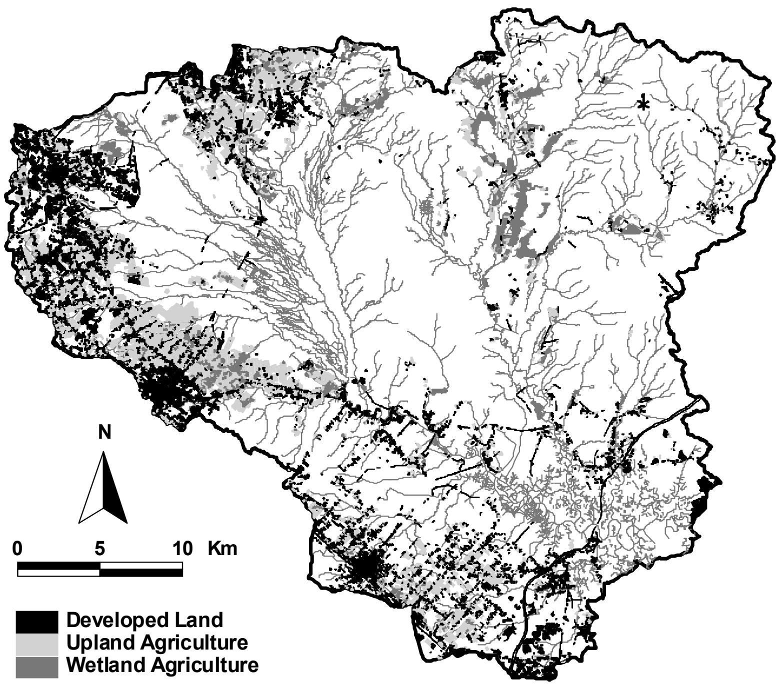

Figure 3. Developed land, upland agriculture, and wetland agriculture in the Mullica River Basin. Unshaded areas represent forest land (uplands, wetlands, and water) and barren land.

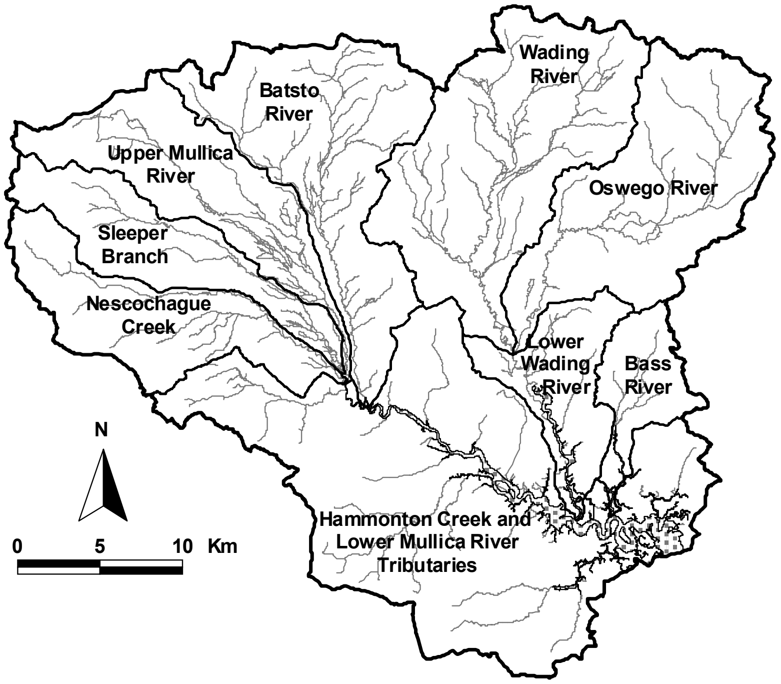

Figure 4. Major drainages of the Mullica River Basin.

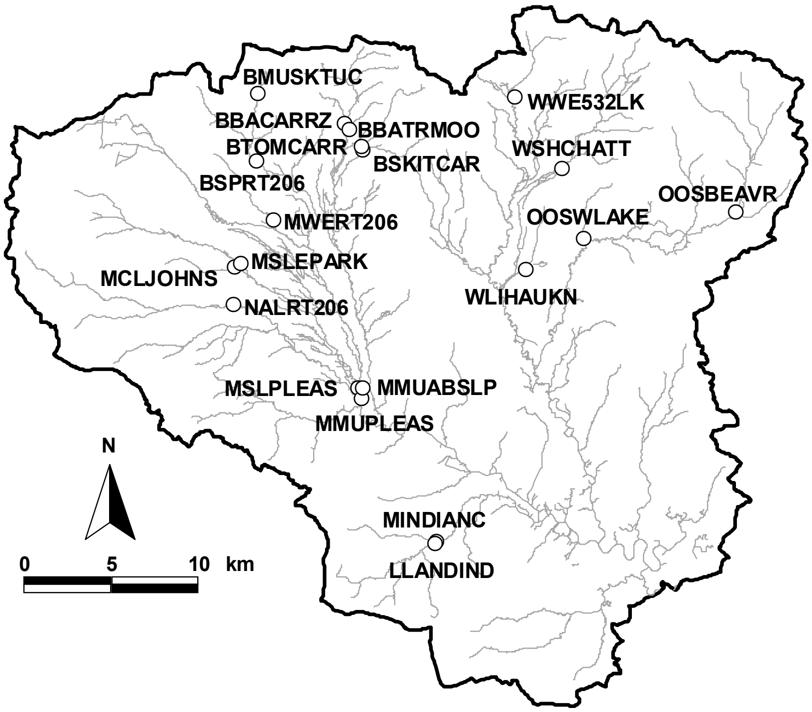

Figure 5. Location of 20 water-quality validation sites. Refer to Table 2 for site descriptions.

Table 2.Validation-site water-quality data. All medians except pH and specific conductance ($\mu S\ cm^{-1}$) are mg L^{-1}. Ammonia and nitrite+nitrate concentrations are expressed as nitrogen.

		Median Water-quality Values								
Stream Station	Site Code	pH	Specific Conductance	Calcium	Magnesium	Chloride	Sulfate	Ammonia	Nitrite + Nitrate	Total P
Oswego River basin										
Oswego River below Beaver Dam Road	OOSBEAVR	4.2	47	0.50	0.37	7.7	-	<0.10	<0.04	0.01
Oswego Lake	OOSWLAKE	4.3	42	0.67	0.35	4.2	-	<0.10	<0.04	0.01
Wading River basin										
Little Hauken Run below Route 563	WLIHAUKN	4.3	45	0.83	0.53	5.6	-	0.11	<0.04	0.02
Shoal Branch at Chatsworth-Tuckerton Road	WSHCHATT	4.3	44	0.43	0.34	4.3	-	<0.10	<0.04	0.02
Wading River at Rt. 532	WWE532LK	4.2	49	0.40	0.36	4.7	-	0.14	<0.04	0.01
Nescochague Creek basin										
Albertson Brook at Rt. 206	NALRT206	6.0	65	-	-	-	6.6	0.07	0.67	-
Sleeper Branch basin										
Clark Branch at Parkdale	MCLJOHNS	4.6	44	-	-	-	6.8	<0.10	<0.20	-
Sleeper Branch at Parkdale	MSLEPARK	6.4	61	1.56	1.36	9.6	-	0.13	0.74	0.01
Sleeper Branch above Mullica River	MSLPLEAS	4.2	62	1.01	0.61	6.1	-	0.11	<0.20	0.01
Mullica River basin										
Landing Creek above Indian Cabin Road	LLANDIND	4.9	78	-	-	-	9.3	0.07	0.57	-
Indian Cabin Creek at Rt. 563	MINDIANC	4.2	67	-	-	-	8.8	0.03	<0.20	-
Mullica River above Sleeper	MMUABSLP	4.9	46	1.32	0.73	6.1	-	0.11	0.07	0.01
Mullica River at Pleasant Mills, Rt. 542	MMUPLEAS	4.8	53	2.00	1.08	6.9	-	0.12	0.17	0.01
Wesickaman Creek at Rt. 206	MWERT206	4.3	74	2.00	0.85	8.7	-	0.10	<0.04	0.03
Batsto River basin										
Batsto River above Carranza Road	BBACARRZ	4.7	61	1.90	1.17	5.7	-	<0.10	0.46	0.01
Batsto River tributary near Moore's Meadow Road	BBATRMOO	4.1	67	1.00	0.49	4.8	-	<0.10	0.05	0.01
Muskingum Brook above Tuckerton Road	BMUSKTUC	6.0	120	8.00	3.34	13.4	-	0.19	1.47	0.03
Skit Branch above Carranza Road	BSKITCAR	4.5	29	0.50	0.35	2.8	-	<0.10	<0.04	0.01
Springers Brook at Route 206	BSPRT206	6.5	142	8.72	2.99	16.1	-	0.11	0.69	0.04
Tom Roberts Branch Above Carranza Road	BTOMCARR	4.3	40	0.50	0.29	3.5	-	<0.10	<0.04	0.01

Table 3. New Jersey Department of Environmental Protection land-use/land-cover classes and the revised Pinelands terminology.

Pinelands classes	NJDEP classes	Code	Subclasses (NJDEP 95 Label)
Developed land	Urban	1110	Residential, high density, multiple dwelling
		1120	Residential, single unit, medium density
		1130	Residential, single unit, low density
		1140	Residential, rural, single unit
		1150	Mixed residential
		1200	Commercial/services
		1211	Military reservations
		1300	Industrial
		1400	Transportation/communications/utilities
		1600	Mixed urban or built-up land
		1700	Other urban or built-up land
		1800	Recreational land
		1804	Athletic fields (schools)
Upland agriculture	Agriculture	2100	Cropland and pastureland
		2300	Confined feeding operations
		2400	Other agriculture
		2200	Orchards/vineyards/nurseries/horticultural areas
Wetland agriculture	Wetlands	2140	Agricultural wetlands (modified)
Barren land	Barren land	7100	Beaches
		7300	Extractive mining
		7400	Altered lands
		7500	Transitional areas
		7600	Undifferentiated barren lands
Upland forest	Forest	4110	Deciduous forest (10-50% crown closure)
		4120	Deciduous forest (>50% crown closure)
		4210	Coniferous forest (10-50% crown closure)
		4220	Coniferous forest (>50% crown closure)
		4230	Plantation
		4311	Mixed forest (>50% coniferous with 10%-50% crown closure)
		4312	Mixed forest (>50% coniferous with >50% crown closure)
		4321	Mixed forest (>50% deciduous with 10-50% crown closure)
		4322	Mixed forest (>50% deciduous with >50% crown closure)
		4410	Old field (< 25% brush covered)
		4420	Deciduous brush/shrubland
		4430	Coniferous brush/shrubland
		4440	Mixed deciduous/coniferous brush/shrubland
		4500	Severe burned upland vegetation
Water	Water	5100	Streams and canals
		5200	Natural lakes
		5300	Artificial lakes
		5410	Tidal rivers, inland bays, and other tidal waters
		5420	Dredged lagoon
		5430	Atlantic ocean
Wetlands	Wetlands	1461	Wetland rights-of-way (modified)
		1750	Managed wetland in maintained lawn greenspace
		1850	Managed wetland in built-up maintained rec area
		2150	Former agricultural wetland (becoming shrubby, not built-up)
		6210	Deciduous wooded wetlands
		6220	Coniferous wooded wetlands
		6221	Atlantic white cedar swamp
		6231	Deciduous scrub/shrub wetlands
		6232	Coniferous scrub/shrub wetlands
		6233	Mixed scrub/shrub wetlands (deciduous dom.)
		6234	Mixed scrub/shrub wetlands (coniferous dom.)
		6240	Herbaceous wetlands
		6251	Mixed forested wetlands (deciduous dom.)
		6252	Mixed forested wetlands (coniferous dom.)
		6500	Severe burned wetlands
		7430	Disturbed wetlands (modified)
		6110	Saline marshes
		6120	Freshwater tidal marshes
		6130	Vegetated dune communities

Table 4. Landsat Thematic Mapper (TM) land-cover classification scheme and the revised Pinelands terminology.

Pinelands classes	TM classes
Developed land	Developed land: high intensity (approx. >75% developed surface)
	Developed land: moderate intensity (approx. 50-75% developed surface)
	Developed land: low-intensity wooded (approx. 25-50% developed surface)
	Developed land: low-intensity unwooded (approx. 25-50% developed surface)
Upland agriculture	Cultivated land: actively tilled
Wetland agriculture [1]	Cultivated land: vines/bushes
Upland forest	Grassland
	Woody land: coniferous >75%
	Woody land: mixed coniferous-deciduous
	Woody land: deciduous >75%
	Woody land: scrub/shrub-mixed
	Barren land
Wetlands	Unconsolidated shore: sand/mud
	Emergent wetlands
	Hardwood swamp
	Pitch pine lowland
	Mixed hardwood-pine-cedar-holly
	White cedar swamp
	Mixed deciduous/conifer scrub/shrub
	Water

[1] Predominantly blueberry and cranberry agriculture

Table 5. Raw DCA axis 1 and 2 site scores for 72 stream-vegetation monitoring sites in the Mullica River basin based on an ordiantion of plant species presence/absence data (Zampella et al. 2001). Sites are ordered by raw axis 1 ordination scores.

Basin	Site	Site code	Axis 1	Axis 2
Batsto River	Deep Run below Hampton Road	BDEEPDKE	0	15
Wading River	Tulpehocken Creek above Maxwell-Friendship Road	WTUHAWKN	6	74
Upper Mullica River	Mullica River below Constable Bridge	MMUCONST	12	27
Batsto River	Penn Swamp Branch above Batona Trail bridge	BPEBRIDG	13	153
Batsto River	Skit Branch below Carranza Road	BSKITCAR	17	141
Wading River	Shane Branch above fourth dike above Carranza Road	WSA4DIKE	24	122
Lower Mullica River	Clarks Mill Stream at Leibig Street and Odessa Avenue	LCLODESS	33	146
Oswego River	Buck Run below Old Martha Road	OBUCKRUN	33	173
Sleeper Branch	Sleeper Branch above Mullica River	MSLPLEAS	34	53
Wading River	Shane Branch above Carranza Road	WSACARRA	40	49
Batsto River	Skit Branch above Hampton Road	BSKITHAM	41	66
Batsto River	Batsto River below Penn Swamp Branch	BBAPENNS	42	34
Oswego River	Oswego River below Beaver Dam Road	OOSBEAVR	44	158
Oswego River	Oswego River below Route 679	OOSHARST	45	66
Oswego River	Oswego River above Martha	OOSOLMAR	46	66
Wading River	Wading River below Ford Road	WWEFORDR	48	34
Batsto River	Batsto River below Central New Jersey/Conrail railroad bridge	BBARRBRG	52	46
Wading River	Wading River above Route 563	WWEEVANB	56	28
Upper Mullica River	Mullica River above dike below Old Jackson-Atsion Road	MMUDIKES	56	66
Wading River	Featherbed Branch below Carranza Road	WFEACARR	56	131
Oswego River	Oswego River above Oswego Lake	OOSLAKUP	60	121
Batsto River	Batsto River tributary above Carranza Road	BBATRCAR	63	78
Batsto River	Batsto River tributary near Moore's Meadow Road	BBATRMOO	64	192
Upper Mullica River	Mullica River at northern border of Wilderness Area	MMUWILDR	71	0
Batsto River	Batsto River above Hampton Road	BBATHAMP	72	45
Sleeper Branch	Clark Branch at Parkdale	MCLJOHNS	76	76
Bass River	East Branch Bass River above Stage Road	AEASTAGE	79	168
Batsto River	Batsto River side channel below Quaker Bridge Road	BBAQUAKR	80	57
Bass River	West Branch Bass River above Stage Road	AWESTAGE	82	127
Wading River	Wading River above Tulpehocken Creek	WWETULPC	83	62
Batsto River	Batsto River tributary below Hay Road	BBATRMAN	84	160
Wading River	Wading River below Mile Run	WWEMILER	85	95
Batsto River	Roberts (Tom Roberts) Branch below Carranza Road	BTOMCARR	85	127
Oswego River	Papoose Branch below Jenkins Road	OPAPOOSE	86	171
Sleeper Branch	Sleeper Branch diversion (Saltars Ditch)	MSLSALTD	93	142
Batsto River	Batsto River at Lower Forge	BBALFORG	95	46
Sleeper Branch	Sleeper Branch at Parkdale	MSLEPARK	98	80
Wading River	Hospitality Brook below Route 563	WHOSPITA	106	63
Sleeper Branch	Clark Branch above Burnt Mill Road	MCLBURNT	106	177
Nescochague Creek	Pump Branch above dike near Winslow/Waterford boundary	NPUMDIKE	107	48
Wading River	Little Hauken Run below Route 563	WLIHAUKN	114	83
Upper Mullica River	Mullica River above Route 534	MMULJACK	119	115
Batsto River	Batsto River below Route 532	BBART532	126	101
Sleeper Branch	Cooper Branch above Burnt Mill Road	MCOBURNT	127	145
Nescochague Creek	Nescochague Creek at Pleasant Mills	NNEMILLS	132	31
Lower Mullica River	Indian Cabin Creek above Landing Creek	LINCABIN	137	131
Upper Mullica River	Mullica River above Central New Jersey/Conrail railroad bridge	MMURRBRG	143	114
Upper Mullica River	Mullica River tributary above Quaker Bridge Road	MMUTRQUA	155	93
Batsto River	Batsto River above Carranza Road	BBACARRZ	168	73
Nescochague Creek	Nescochague Creek near West Mill Road	NNEWESTM	174	57
Batsto River	Springers Brook below Deep Run	BSPRDIKE	178	46
Lower Mullica River	Morses Mill Stream below College Drive	LMORSESM	182	97
Nescochague Creek	Albertson Brook above derelict bridge below Route 206	NALDEREL	187	107
Lower Mullica River	Elliots Creek at Bremen Avenue	LELIOBRE	187	135
Sleeper Branch	Price Branch below Burnt Mill Road	MPRBURNT	204	125
Sleeper Branch	Sleeper Branch at Maple Island	MSLMAPLE	206	112
Batsto River	Indian Mills Brook above Oakshade Road (above Shadow Lake)	BINSHADS	222	97
Lower Mullica River	Landing Creek below Alternate Route 561	LLANDMOS	223	79
Nescochague Creek	Albertson Brook above Fleming Pike	NALBFLEM	227	75
Sleeper Branch	Hays Mill Creek above Tremont Avenue	MHATREMO	232	119
Sleeper Branch	Wildcat Branch below Burnt Mill Road	MWIBURNT	236	133
Batsto River	Springers Brook above Hampton Road	BSPRIHAM	243	47
Lower Mullica River	Landing Creek above Indian Cabin Road	LLANDIND	244	87
Upper Mullica River	Mullica River below Jackson-Medford Road	MMULADYS	250	92
Nescochague Creek	Blue Anchor Brook above Pump Branch	NBLCONFL	255	111
Nescochague Creek	Great Swamp Branch below Route 613	NGRMIDDL	271	71
Upper Mullica River	Wesickaman Creek below Three Bridge Road	MWETHREE	288	126
Lower Mullica River	Union Creek above Alternate Route 561	LUNIOMOS	294	115
Batsto River	Horse Pond Stream below Butterworth's Bogs Road	BHOBUTTR	306	96
Lower Mullica River	Hammonton Creek above Chestnut Avenue	LHACHEST	316	67
Batsto River	Muskingum Brook above Tuckerton Road	BMUSKTUC	336	46
Nescochague Creek	Cedar Brook near Hammonton Airport	NCEAIRPO	347	112

Table 6. Raw DCA axis 1 and axis 2 site scores for 54 stream sites in the Mullica River basin based on an ordination of stream-fish species presence/absence data (Zampella et al. 2001). Sites are ordered by raw DCA axis 1 scores.

Basin	Site	Site Code	Axis 1	Axis 2
Batsto River	Roberts (Tom Roberts) Branch below Carranza Road	BTOMCARR	0	28
Batsto River	Skit Branch below Carranza Road	BSKITCAR	3	60
Oswego River	Oswego River below Beaver Dam Road	OOSBEAVR	3	35
Wading River	Little Hauken Run below Route 563	WLIHAUKN	4	39
Batsto River	Skit Branch above Hampton Road	BSKITHAM	10	66
Batsto River	Batsto River below Central New Jersey/Conrail railroad bridge	BBARRBRG	11	89
Oswego River	Oswego River below Route 679	OOSHARST	11	89
Oswego River	Oswego River above Oswego Lake	OOSLAKUP	13	92
Oswego River	Oswego River above Martha	OOSOLMAR	13	92
Wading River	Hospitality Brook below Route 563	WHOSPITA	17	23
Upper Mullica River	Mullica River above dike below Old Jackson-Atsion Road	MMUDIKES	18	36
Upper Mullica River	Mullica River above Route 534	MMULJACK	18	36
Oswego River	Buck Run below Old Martha Road	OBUCKRUN	21	121
Wading River	Featherbed Branch below Carranza Road	WFEACARR	22	22
Wading River	Tulpehocken Creek above Maxwell-Friendship Road	WTUHAWKN	22	72
Wading River	Wading River above Route 563	WWEEVANB	22	72
Bass River	East Branch Bass River above Stage Road	AEASTAGE	23	93
Wading River	Wading River below Mile Run	WWEMILER	25	54
Upper Mullica River	Mullica River at northern border of Wilderness Area	MMUWILDR	30	72
Sleeper Branch	Sleeper Branch above Mullica River	MSLPLEAS	31	95
Oswego River	Papoose Branch below Jenkins Road	OPAPOOSE	31	66
Lower Mullica River	Elliots Creek at Bremen Avenue	LELIOBRE	32	49
Wading River	Wading River above Tulpehocken Creek	WWETULPC	34	65
Batsto River	Batsto River below Penn Swamp Branch	BBAPENNS	35	116
Wading River	Wading River below Ford Road	WWEFORDR	35	48
Batsto River	Batsto River above Carranza Road	BBACARRZ	40	101
Sleeper Branch	Clark Branch at Parkdale	MCLJOHNS	42	99
Upper Mullica River	Mullica River below Constable Bridge	MMUCONST	42	81
Batsto River	Batsto River side channel below Quaker Bridge Road	BBAQUAKR	44	120
Lower Mullica River	Landing Creek above Indian Cabin Road	LLANDIND	47	75
Nescochague Creek	Nescochague Creek at Pleasant Mills	NNEMILLS	47	75
Batsto River	Batsto River at Lower Forge	BBALFORG	48	121
Lower Mullica River	Union Creek above Alternate Route 561	LUNIOMOS	48	54
Bass River	West Branch Bass River above Stage Road	AWESTAGE	49	23
Sleeper Branch	Sleeper Branch at Parkdale	MSLEPARK	49	66
Lower Mullica River	Indian Cabin Creek above Landing Creek	LINCABIN	50	117
Upper Mullica River	Mullica River below Central New Jersey/Conrail railroad bridge	MMURRBRG	50	63
Batsto River	Batsto River above Hampton Road	BBATHAMP	54	98
Lower Mullica River	Landing Creek below Alternate Route 561	LLANDMOS	55	88
Batsto River	Springers Brook below Deep Run	BSPRDIKE	67	85
Upper Mullica River	Wesickaman Creek below Three Bridge Road	MWETHREE	74	11
Sleeper Branch	Hays Mill Creek above Tremont Avenue	MHATREMO	76	115
Upper Mullica River	Mullica River below Jackson-Medford Road	MMULADYS	84	0
Nescochague Creek	Pump Branch above dike near Winslow/Waterford boundary	NPUMDIKE	86	110
Batsto River	Springers Brook above Hampton Road	BSPRIHAM	87	36
Nescochague Creek	Nescochague Creek near West Mill Road	NNEWESTM	88	58
Nescochague Creek	Great Swamp Branch below Route 613	NGRMIDDL	93	66
Nescochague Creek	Albertson Brook above derelict bridge below Route 206	NALDEREL	101	70
Lower Mullica River	Morses Mill Stream below College Drive	LMORSESM	104	14
Nescochague Creek	Cedar Brook near Hammonton Airport	NCEAIRPO	108	28
Nescochague Creek	Albertson Brook above Fleming Pike	NALBFLEM	115	136
Batsto River	Indian Mills Brook above Oakshade Road (above Shadow Lake)	BINSHADS	118	0
Batsto River	Muskingum Brook above Tuckerton Road	BMUSKTUC	121	56
Lower Mullica River	Hammonton Creek above Chestnut Avenue	LHACHEST	125	62

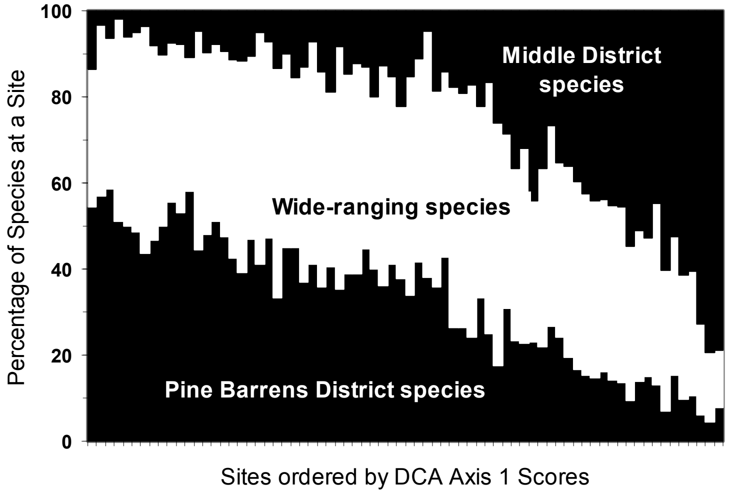

Figure 6a. Biogeography of plants found at 72 Mullica River Basin stream sites. Wide-ranging species are native to both the Pine Barrens District and the adjacent Middle District. Refer to Table 5 for site names ordered by DCA axis 1 scores.

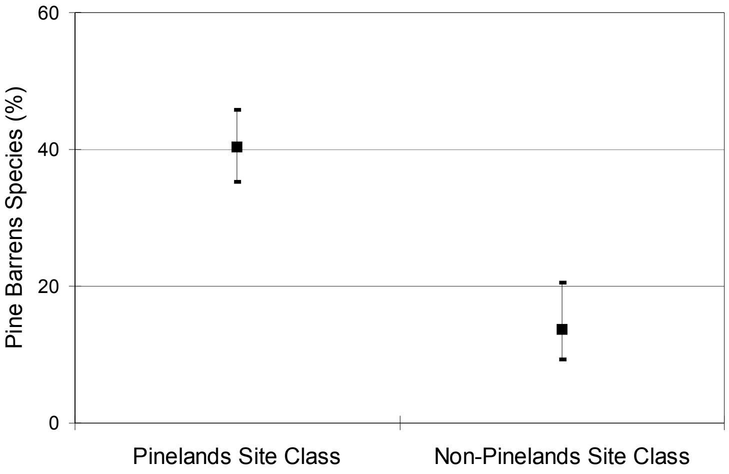

Figure 6b. The percentage of Pine Barrens, wide-ranging and non-Pine Barrens (Middle District) plant species in TWINSPAN-derived site classes for 72 Mullica River Basin stream sites.

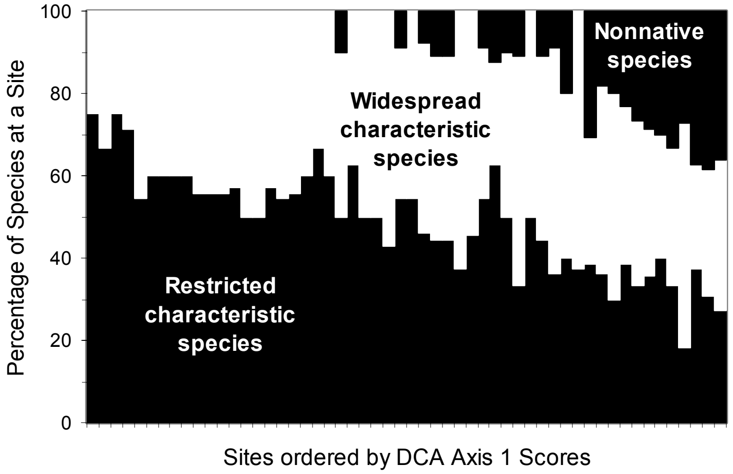

Figure 7a. Biogeography of fish found at 54 Mullica River Basin stream sites. Refer to Table 5 for site names ordered by DCA axis 1 scores.

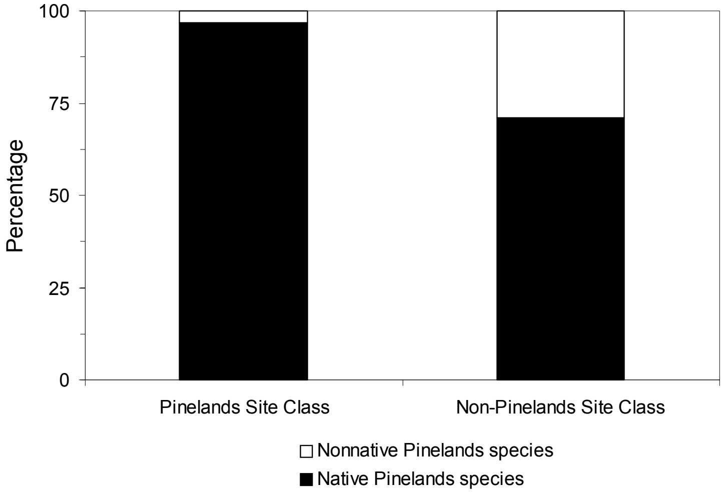

Figure 7b. The percentage of native and nonnative fish species in TWINSPAN-derived site classes for 54 Mullica River Basin stream sites.

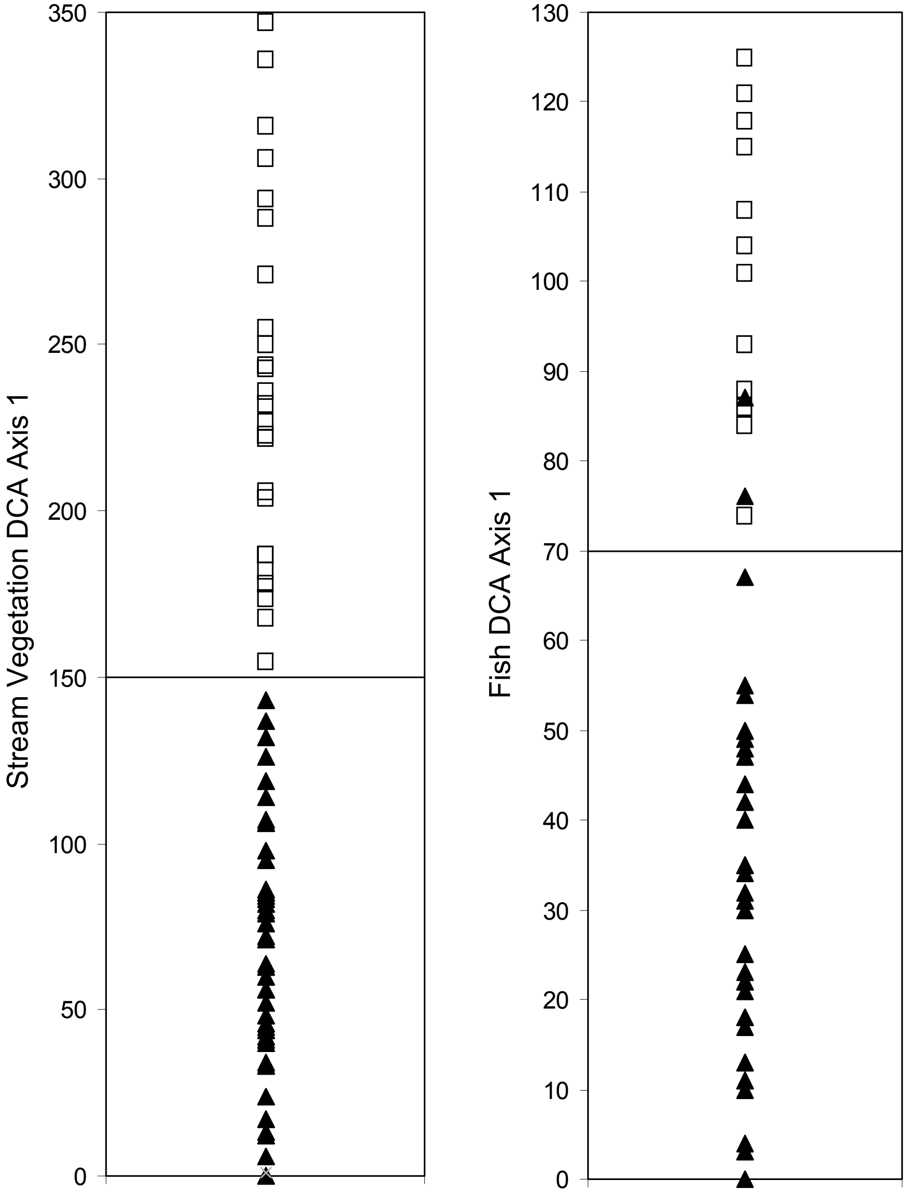

Figure 8. Relationship of stream-vegetation and stream-fish assemblage DCA axis 1 scores to TWINSPAN-derived site classes. Refer to table 5b and 6b for the composition of TWINSPAN-derived site classes.

Table 7a. ITUM calcium models based on 25 USGS stations. Model concentrations are in microequivalents per liter. R-square values are shown in parentheses.

All land uses included in the analysis.

				Regression Coefficients and R-square Values						
Model Type	Model R^2	PRESS	Intercept	Developed Lands	Upland Agriculture	Wetland Agriculture	Barren Lands	Upland Forest	Water	Wetlands
1986 DEM	0.91	49519	3.39	-	-	-	-	-0.02 (0.76)	-0.10 (0.02)	-0.01 (0.13)
1995 DEM	0.92	45693	3.35	-	-	-	-	-0.02 (0.77)	-0.09 (0.02)	-0.01 (0.13)
1986 DWI	0.78	53258	2.91	-	-	-	-	-0.02 (0.78)	-	-
1995 DWI	0.78	50195	2.88	-	-	-	-	-0.02 (0.78)	-	-
1986 DWS	0.86	58770	3.21	-	-	-	-	-0.02 (0.77)	-	-0.01 (0.09)
1995 DWS	0.86	52956	3.17	-	-	-	-	-0.02 (0.78)	-	-0.01 (0.08)

Only developed land, upland agriculture, and barren land included in the analysis.

				Regression Coefficients and R-square Values		
Model Type	Model R^2	PRESS	Intercept	Developed Lands	Upland Agriculture	Barren Lands
1986 DEM	0.86	87342	1.48	0.02 (0.18)	0.02 (0.68)	-
1995 DEM	0.88	74676	1.47	0.02 (0.21)	0.02 (0.66)	-
1986 DWI	0.69	180226	1.59	-	0.03 (0.69)	-
1995 DWI	0.72	196966	1.57	0.01 (0.07)	0.02 (0.65)	-
1986 DWS	0.82	94429	1.51	0.02 (0.16)	0.02 (0.66)	-
1995 DWS	0.83	82875	1.51	0.02 (0.20)	0.02 (0.64)	-

Table 7b. ITUM magnesium models based on 25 USGS stations. Model concentrations are in microequivalents per liter. R-square values are shown in parentheses.

All land uses included in the analysis.

				Regression Coefficients and R-square Values						
Model Type	Model R^2	PRESS	Intercept	Developed Lands	Upland Agriculture	Wetland Agriculture	Barren Lands	Upland Forest	Water	Wetlands
1986 DEM	0.88	51007	1.51	0.01 (0.16)	0.02 (0.72)	-	-	-	-	-
1995 DEM	0.91	22874	3.21	-	-	-	-0.10 (0.03)	-0.02 (0.70)	-	-0.02 (0.18)
1986 DWI	0.80	43849	2.27	-	0.01 (0.05)	-	-	-0.01 (0.74)	-	-
1995 DWI	0.79	42451	2.32	-	0.01 (0.04)	-	-	-0.01 (0.74)	-	-
1986 DWS	0.88	25341	3.28	-	-	-	-	-0.02 (0.72)	-0.07 (0.03)	-0.01 (0.13)
1995 DWS	0.88	30427	3.21	-	-	-	-0.09 (0.03)	-0.02 (0.73)	-	-0.01 (0.12)

Only developed land, upland agriculture, and barren land included in the analysis.

				Regression Coefficients and R-square Values		
Model Type	Model R^2	PRESS	Intercept	Developed Lands	Upland Agriculture	Barren Lands
1986 DEM	0.88	51007	1.51	0.01 (0.16)	0.02 (0.72)	-
1995 DEM	0.91	40226	1.52	0.02 (0.19)	0.02 (0.70)	-0.08 (0.02)
1986 DWI	0.71	88740	1.61	-	0.03 (0.71)	-
1995 DWI	0.75	89930	1.58	0.01 (0.08)	0.02 (0.65)	-
1986 DWS	0.85	48615	1.54	0.01 (0.14)	0.02 (0.71)	-
1995 DWS	0.86	43684	1.54	0.01 (0.18)	0.02 (0.68)	-

Table 7c. ITUM chloride models based on 25 USGS stations. Model concentrations are in microequivalents per liter. R-square values are shown in parentheses.

All land uses included in the analysis.

Model Type	Model R^2	PRESS	Intercept	Regression Coefficients and R-square Values						
				Developed Lands	Upland Agriculture	Wetland Agricult	Barren Lands	Upland Forest	Water	Wetlands
1986 DEM	0.88	65576	2.40	0.01 (0.81)	-	-	-	-0.005 (0.07)	-	-
1995 DEM	0.89	70592	2.37	0.01 (0.83)	-	-	-	-0.005 (0.06)	-	-
1986 DWI	0.84	129491	2.95	-	-	-0.05	-	-0.01 (0.79)	-	-
1995 DWI	0.84	131861	2.93	-	-	-0.05	-	-0.01 (0.79)	-	-
1986 DWS	0.88	57648	2.46	0.01 (0.78)	-	-	-	-0.01 (0.10)	-	-
1995 DWS	0.88	76486	2.45	0.01 (0.79)	-	-	-	-0.01 (0.09)	-	-

Only developed land, upland agriculture, and barren land included in the analysis.

Model Type	Model R^2	PRESS	Intercept	Regression Coefficients and R-square Values		
				Developed Lands	Upland Agriculture	Barren Lands
1986 DEM	0.87	71544	2.06	0.02 (0.81)	0.005 (0.06)	-
1995 DEM	0.88	77029	2.06	0.02 (0.83)	0.005 (0.05)	-
1986 DWI	0.70	340822	2.12	0.01 (0.63)	0.01 (0.08)	-
1995 DWI	0.71	316586	2.12	0.01 (0.64)	0.01 (0.08)	-
1986 DWS	0.85	89980	2.08	0.02 (0.78)	0.01 (0.07)	-
1995 DWS	0.85	108450	2.08	0.02 (0.79)	0.01 (0.06)	-

Table 7d. ITUM sulfate models based on 25 USGS stations. Model concentrations are in microequivalents per liter. R-square values are shown in parentheses.

All land uses included in the analysis.

Model Type	Model R^2	PRESS	Intercept	Regression Coefficients and R-square Values		
				Developed Lands	Upland Agriculture	Barren Lands
1986 DEM	0.54	66837	1.95	-	0.01 (0.54)	-
1995 DEM	0.56	58520	1.95	-	0.01 (0.56)	-
1986 DWI	0.44	98498	1.96	-	0.01 (0.44)	-
1995 DWI	0.45	93300	1.96	-	0.01 (0.45)	-
1986 DWS	0.50	74902	1.96	-	0.01 (0.50)	-
1995 DWS	0.52	67418	1.96	-	0.01 (0.52)	-

Only developed land, upland agriculture, and barren land included in the analysis.

Model Type	Model R^2	PRESS	Intercept	Regression Coefficients and R-square Values		
				Developed Lands	Upland Agriculture	Barren Lands
1986 DEM	0.54	66837	1.95	.	0.01 (0.54)	-
1995 DEM	0.56	58520	1.95	.	0.01 (0.56)	-
1986 DWI	0.44	98498	1.96	.	0.01 (0.44)	-
1995 DWI	0.45	93300	1.96	.	0.01 (0.45)	-
1986 DWS	0.50	74902	1.96	.	0.01 (0.50)	-
1995 DWS	0.52	67418	1.96	.	0.01 (0.52)	-

Table 7e. ITUM specific conductance models based on 25 USGS stations. Model concentrations are in microequivalents per liter. R-square values are shown in parentheses.

All land uses included in the analysis.

				Regression Coefficients and R-square Values						
Model Type	Model R^2	PRESS	Intercept	Developed Lands	Upland Agriculture	Wetland Agriculture	Barren Lands	Upland Forest	Water	Wetlands
1986 DEM	0.82	6212	1.60	0.01 (0.65)	0.01 (0.18)	-	-	-	-	-
1995 DEM	0.84	5870	1.59	0.01 (0.68)	0.01 (0.16)	-	-	-	-	-
1986 DWI	0.83	3163	2.22	-	-	-	-	-0.01 (0.83)	-	-
1995 DWI	0.83	3263	2.21	-	-	-	-	-0.01 (0.83)	-	-
1986 DWS	0.81	5568	2.33	-	-	-	-	-0.01 (0.68)	-	-0.01 (0.13)
1995 DWS	0.81	5330	2.32	-	-	-	-	-0.01 (0.69)	-	-0.01 (0.13)

Only developed land, upland agriculture, and barren land included in the analysis.

				Regression Coefficients and R-square Values		
Model Type	Model R^2	PRESS	Intercept	Developed Lands	Upland Agriculture	Barren Lands
1986 DEM	0.82	6212	1.60	0.01 (0.65)	0.01 (0.18)	-
1995 DEM	0.84	5870	1.59	0.01 (0.68)	0.01 (0.16)	-
1986 DWI	0.71	11914	1.63	0.01 (0.10)	0.01 (0.61)	-
1995 DWI	0.72	11425	1.63	0.01 (0.14)	0.01 (0.58)	-
1986 DWS	0.81	6795	1.61	0.01 (0.62)	0.01 (0.18)	-
1995 DWS	0.82	6516	1.61	0.01 (0.64)	0.01 (0.18)	-

Table 7f. ITUM pH models based on 25 USGS stations. Model concentrations are in microequivalents per liter. R-square values are shown in parentheses.

All land uses included in the analysis.

				Regression Coefficients and R-square Values						
Model Type	Model R^2	PRESS	Intercept	Developed Lands	Upland Agriculture	Wetland Agriculture	Barren Lands	Upland Forest	Water	Wetlands
1986 DEM	0.85	4.27	4.29	0.06 (0.71)	0.03 (0.14)	-	-	-	-	-
1995 DEM	0.87	3.90	4.29	0.06 (0.75)	0.03 (0.12)	-	-	-	-	-
1986 DWI	0.85	4.36	6.27	0.05 (0.73)	-	-	-	-0.03 (0.12)	-	-
1995 DWI	0.86	4.00	6.23	0.05 (0.74)	-	-	-	-0.03 (0.12)	-	-
1986 DWS	0.89	3.30	4.33	0.06 (0.73)	0.03 (0.16)	-	-	-	-	-
1995 DWS	0.90	3.05	4.33	0.06 (0.76)	0.03 (0.14)	-	-	-	-	-

Only developed land, upland agriculture, and barren land included in the analysis.

				Regression Coefficients and R-square Values		
Model Type	Model R^2	PRESS	Intercept	Developed Lands	Upland Agriculture	Barren Lands
1986 DEM	0.85	4.27	4.29	0.06 (0.71)	0.03 (0.14)	-
1995 DEM	0.87	3.90	4.29	0.06 (0.75)	0.03 (0.12)	-
1986 DWI	0.83	4.95	4.46	0.06 (0.73)	0.04 (0.10)	-
1995 DWI	0.85	4.47	4.46	0.06 (0.74)	0.04 (0.10)	-
1986 DWS	0.89	3.30	4.33	0.06 (0.73)	0.03 (0.16)	-
1995 DWS	0.90	3.05	4.33	0.06 (0.76)	0.03 (0.14)	-

0

Table 8a. Calcium model-validation results: Wilcoxon matched-pairs tests. Asterisks denote those tests significant after the Bonferonni correction.

1986 Wilcoxon matched-pairs-test results.

	N	p-level
1986 DEM & 1986 DWI	16	0.056
1986 DEM & 1986 DWS	16	0.026
1986 DWI & 1986 DWS	16	0.301

1995 Wilcoxon matched-pairs-test results.

	N	p-level
1995 DEM & 1995 DWI	16	0.039
1995 DEM & 1995 DWS	16	0.015*
1995 DWI & 1995 DWS	16	0.278

Comparison between model years.

	N	p-level
1986 DEM & 1995 DEM	16	0.301
1986 DWI & 1995 DWI	16	0.026
1986 DWS & 1995 DWS	16	0.196

Summary statistics (mg L^{-1}) for the residuals of each model.

Model Type	N	Mean	Median	Minimum	Maximum	Lower Quartile	Upper Quartile	Quartile Range	S.D.
1986 DEM	16	0.44	0.19	0.03	1.69	0.13	0.77	0.64	0.46
1986 DWI	16	1.09	0.36	0.09	4.20	0.26	1.41	1.15	1.42
1986 DWS	16	0.74	0.45	0.01	2.29	0.29	1.08	0.80	0.73
1995 DEM	16	0.39	0.21	0.03	1.19	0.12	0.61	0.49	0.38
1995 DWI	16	1.04	0.38	0.06	4.21	0.24	1.37	1.12	1.34
1995 DWS	16	0.69	0.45	0.01	2.04	0.25	1.07	0.81	0.65

Table 8b. Magnesium model-validation results: Wilcoxon matched-pairs tests. Asterisks denote those tests significant after the Bonferonni correction.

1986 Wilcoxon matched-pairs-test results.

	N	p-level
1986 DEM & 1986 DWI	16	0.003*
1986 DEM & 1986 DWS	16	0.098
1986 DWI & 1986 DWS	16	0.326

1995 Wilcoxon matched-pairs-test results.

	N	p-level
1995 DEM & 1995 DWI	16	0.196
1995 DEM & 1995 DWS	16	0.003*
1995 DWI & 1995 DWS	16	0.570

Comparison between model years.

	N	p-level
1986 DEM & 1995 DEM	16	0.020
1986 DWI & 1995 DWI	16	0.301
1986 DWS & 1995 DWS	16	0.570

Summary statistics (mg L^{-1}) for the residuals of each model.

Model Type	N	Mean	Median	Minimum	Maximum	Lower Quartile	Upper Quartile	Quartile Range	S.D.
1986 DEM	16	0.16	0.10	0.01	0.87	0.04	0.20	0.16	0.21
1986 DWI	16	0.34	0.28	0.01	1.26	0.09	0.40	0.30	0.34
1986 DWS	16	0.34	0.17	0.00	1.58	0.02	0.45	0.43	0.48
1995 DEM	16	0.31	0.17	0.01	1.69	0.04	0.35	0.31	0.43
1995 DWI	16	0.36	0.25	0.07	1.39	0.13	0.39	0.26	0.37
1995 DWS	16	0.37	0.19	0.01	1.87	0.11	0.47	0.36	0.47

Table 8c. Chloride model-validation results: Wilcoxon matched-pairs tests. Asterisks denote those tests significant after the Bonferonni correction.

1986 Wilcoxon matched-pairs-test results.

	N	p-level
1986 DEM & 1986 DWI	16	0.570
1986 DEM & 1986 DWS	16	0.179
1986 DWI & 1986 DWS	16	0.796

1995 Wilcoxon matched-pairs-test results.

	N	p-level
1995 DEM & 1995 DWI	16	0.535
1995 DEM & 1995 DWS	16	0.163
1995 DWI & 1995 DWS	16	0.918

Comparison between model years.

	N	p-level
1986 DEM & 1995 DEM	16	0.179
1986 DWI & 1995 DWI	16	0.079
1986 DWS & 1995 DWS	16	0.079

Summary statistics (mg L^{-1}) for the residuals of each model.

Model Type	N	Mean	Median	Minimum	Maximum	Lower Quartile	Upper Quartile	Quartile Range	S.D.
1986 DEM	16	1.6	1.2	0.2	5.0	0.6	2.0	1.4	1.3
1986 DWI	16	2.1	1.3	0.1	5.4	0.9	3.2	2.3	1.8
1986 DWS	16	1.7	1.4	0.3	4.0	0.7	2.6	1.9	1.2
1995 DEM	16	1.5	1.3	0.0	3.8	0.6	1.9	1.3	1.2
1995 DWI	16	1.9	1.3	0.1	5.2	0.5	3.1	2.6	1.8
1995 DWS	16	1.6	1.3	0.5	3.7	0.6	2.4	1.8	1.0

Table 8d. Sulfate model-validation results: Wilcoxon matched-pairs tests. Asterisks denote those tests significant after the Bonferonni correction.

1986 Wilcoxon matched-pairs-test results.

	N	p-level
1986 DEM & 1986 DWI	6	0.75
1986 DEM & 1986 DWS	6	0.92
1986 DWI & 1986 DWS	6	0.75

1995 Wilcoxon matched-pairs-test results.

	N	p-level
1995 DEM & 1995 DWI	6	0.75
1995 DEM & 1995 DWS	6	0.75
1995 DWI & 1995 DWS	6	0.75

Comparison between model years.

	N	p-level
1986 DEM & 1995 DEM	6	0.46
1986 DWI & 1995 DWI	6	0.92
1986 DWS & 1995 DWS	6	0.35

Summary statistics (mg L^{-1}) for the residuals of each model.

Model Type	N	Mean	Median	Minimum	Maximum	Lower Quartile	Upper Quartile	Quartile Range	S.D.
1986 DEM	6	2.7	2.4	1.6	4.3	1.9	3.4	1.4	1.0
1986 DWI	6	2.4	2.9	0.2	4.2	1.5	3.1	1.6	1.4
1986 DWS	6	2.7	2.4	1.7	4.3	2.0	3.3	1.3	1.0
1995 DEM	6	2.5	2.5	1.4	3.4	1.8	3.2	1.4	0.8
1995 DWI	6	2.5	2.6	0.8	4.2	1.8	2.9	1.0	1.1
1995 DWS	6	2.5	2.5	1.5	3.6	1.9	3.1	1.2	0.8

Table 8e. Specific conductance model-validation results: Wilcoxon matched-pairs tests. Asterisks denote those tests significant after the Bonferonni correction.

1986 Wilcoxon matched-pairs-test results.

	N	p-level
1986 DEM & 1986 DWI	20	0.126
1986 DEM & 1986 DWS	20	0.296
1986 DWI & 1986 DWS	20	0.332

1995 Wilcoxon matched-pairs-test results.

	N	p-level
1995 DEM & 1995 DWI	20	0.126
1995 DEM & 1995 DWS	20	0.391
1995 DWI & 1995 DWS	20	0.247

Comparison between model years.

	N	p-level
1986 DEM & 1995 DEM	20	0.073
1986 DWI & 1995 DWI	20	0.011*
1986 DWS & 1995 DWS	20	0.021

Summary statistics for the residuals of each model.

Model Type	N	Mean	Median	Minimum	Maximum	Lower Quartile	Upper Quartile	Quartile Range	S.D.
1986 DEM	20	11.5	7.4	0.0	52.7	3.2	17.4	14.1	12.3
1986 DWI	20	16.9	13.0	0.9	56.1	4.6	25.0	20.4	15.4
1986 DWS	20	13.8	12.1	1.8	44.9	5.9	17.8	11.9	10.4
1995 DEM	20	11.1	7.8	0.2	47.2	3.2	17.2	14.0	11.2
1995 DWI	20	16.4	12.6	0.7	50.5	5.8	23.8	18.0	14.4
1995 DWS	20	13.3	12.0	1.3	39.9	6.0	17.6	11.6	9.4

Table 8f. pH model-validation results: Wilcoxon matched-pairs tests. Asterisks denote those tests significant after the Bonferonni correction.

1986 Wilcoxon matched-pairs-test results.

	N	p-level
1986 DEM & 1986 DWI	20	0.023*
1986 DEM & 1986 DWS	20	0.010*
1986 DWI & 1986 DWS	20	0.079

1995 Wilcoxon matched-pairs-test results.

	N	p-level
1995 DEM & 1995 DWI	20	0.014*
1995 DEM & 1995 DWS	20	0.002*
1995 DWI & 1995 DWS	20	0.117

Comparison between model years.

	N	p-level
1986 DEM & 1995 DEM	20	0.037
1986 DWI & 1995 DWI	20	0.263
1986 DWS & 1995 DWS	20	0.145

Summary statistics for the residuals of each model.

Model Type	N	Mean	Median	Minimum	Maximum	Lower Quartile	Upper Quartile	Quartile Range	S.D.
1986 DEM	20	0.39	0.30	0.02	1.09	0.11	0.65	0.54	0.33
1986 DWI	20	0.58	0.45	0.14	1.42	0.32	0.78	0.46	0.36
1986 DWS	20	0.44	0.35	0.04	1.19	0.17	0.69	0.52	0.35
1995 DEM	20	0.37	0.30	0.02	1.08	0.08	0.60	0.52	0.33
1995 DWI	20	0.57	0.43	0.00	1.41	0.32	0.78	0.46	0.37
1995 DWS	20	0.44	0.37	0.07	1.19	0.14	0.66	0.52	0.35

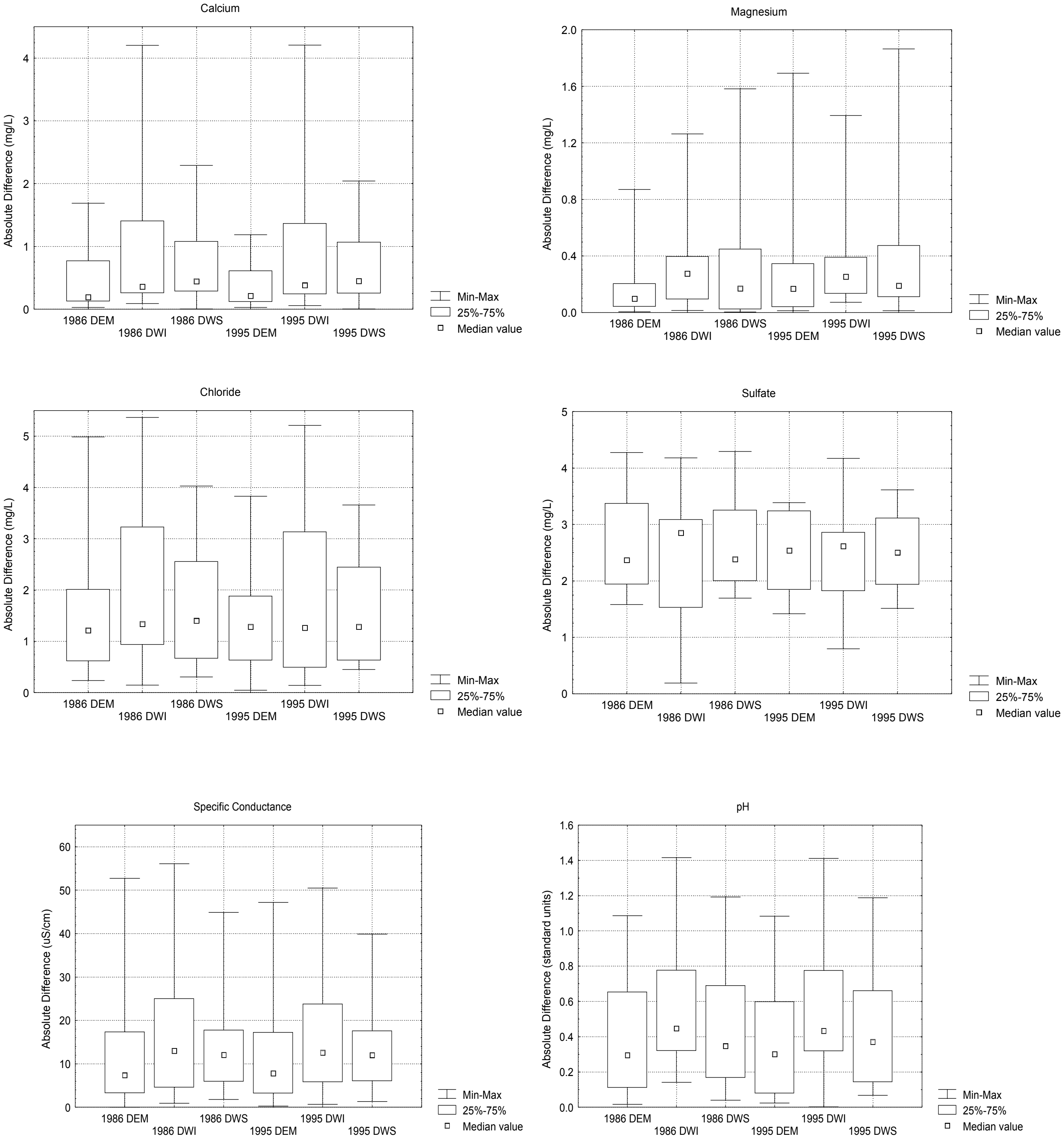

Figure 9. Comparison of absolute residuals (absolute difference between measured and predicted values) from the 1986 and 1995 ITUM land-use/water-quality model-validation analyses.

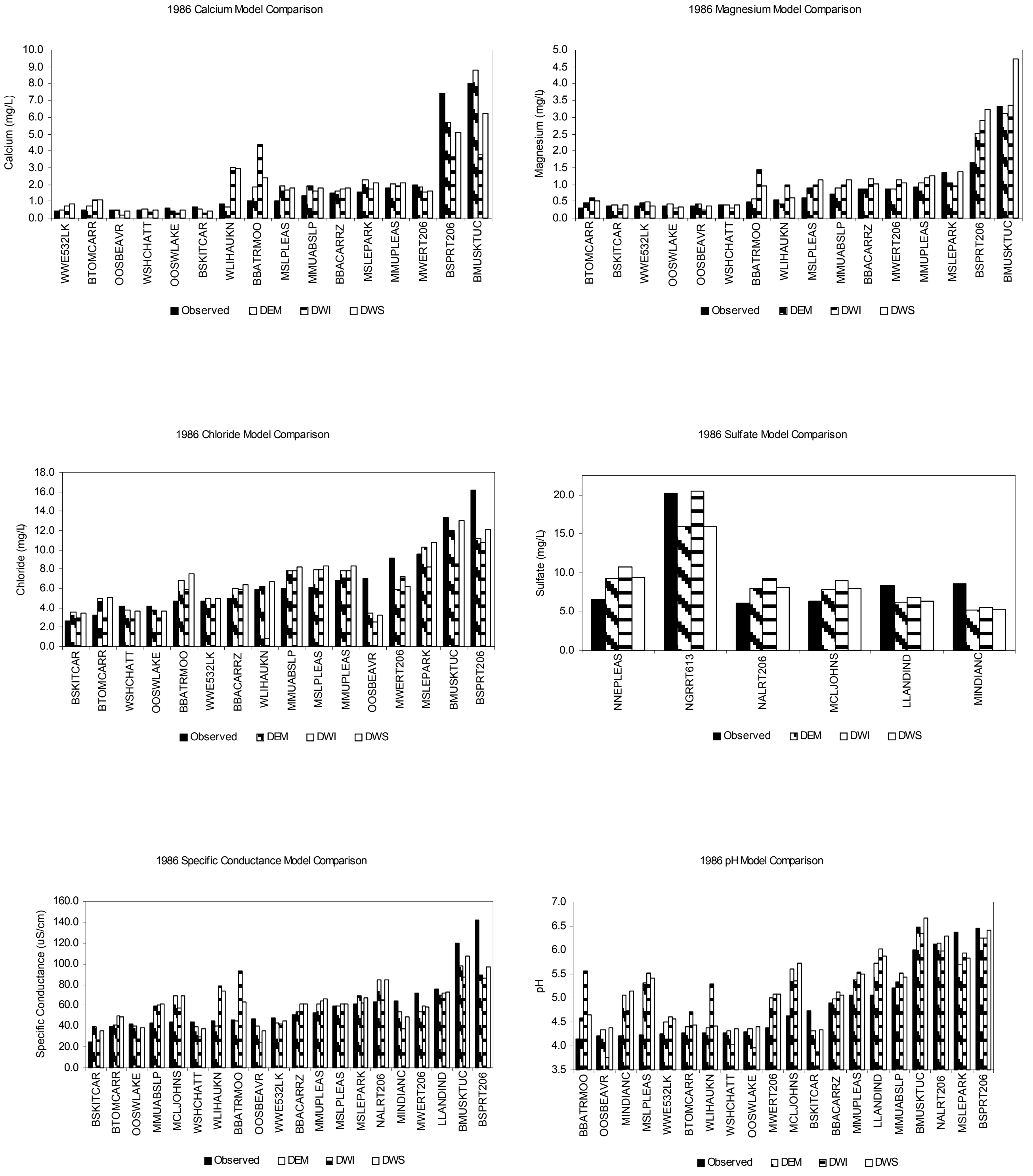

Figure 10a. Comparison of observed and predicted water-quality values from 1986 ITUM land-use/water-quality model-validation analyses. Refer to Table 2 for site names.

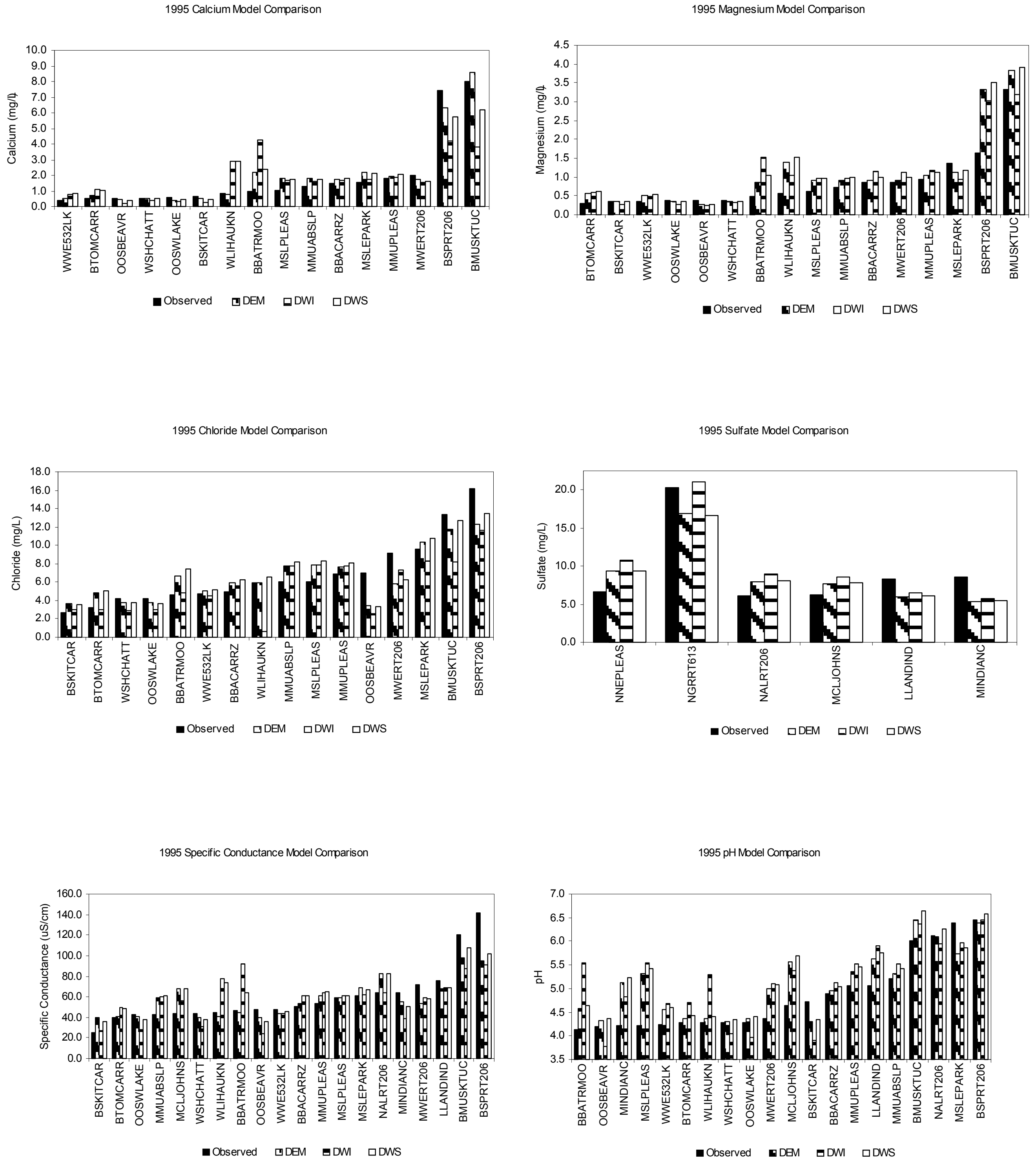

Figure 10b. Comparison of observed and predicted water-quality values from 1995 ITUM land-use/water-quality model-validation analyses. Refer to Table 2 for site names.

Table 9. 1995-ITUM regression models based on flow-weighted water-quality values (FW) and median water-quality values (NO_FW). R-square values are shown in parentheses. Calcium, magnesium, chloride, and sulfate concentrations were expressed in microequivalents per liter for model development.

Parameter	Model	Model R^2	PRESS	Coefficients and R-square Values						
				Developed Lands	Upland Agriculture	Wetland Agriculture	Barren Lands	Upland Forest	Water	Wetlands
Calcium	DEM FW	0.89	40852	-	-	-	-	-0.02 (0.78)	-	-0.01 (0.10)
	DEM NO_FW	0.89	40774	-	-	-	-	-0.02 (0.76)	-	-0.01 (0.12)
	DWI FW	0.72	54290	-	-	-	-	-0.02 (0.72)	-	-
	DWI NO_FW	0.72	52620	-	-	-	-	-0.02 (0.72)	-	-
	DWS FW	0.87	50799	-	0.03 (0.11)	-	-	-0.01 (0.77)	-	-
	DWS NO_FW	0.83	50030	-	-	-	-	-0.02 (0.75)	-	-0.01 (0.09)
Magnesium	DEM FW	0.90	27299	-	-	-	-0.10 (0.04)	-0.02 (0.69)	-	-0.01 (0.17)
	DEM NO_FW	0.89	27367	-	-	-	-0.10 (0.04)	-0.02 (0.65)	-	-0.02 (0.20)
	DWI FW	0.69	40581	-	-	-	-	-0.02 (0.69)	-	-
	DWI NO_FW	0.68	40614	-	-	-	-	-0.02 (0.68)	-	-
	DWS FW	0.89	19372	-	0.03 (0.81)	-	-	-0.01 (0.07)	-	-
	DWS NO_FW	0.86	34556	-	-	-	-0.11 (0.05)	-0.02 (0.66)	-	-0.02 (0.15)
Chloride	DEM FW	0.89	84316	0.02 (0.85)	0.00 (0.04)	-	-	-	-	-
	DEM NO_FW	0.86	75963	0.01 (0.80)	-	-	-	0.00 (0.06)	-	-
	DWI FW	0.84	164757	0.01 (0.11)	-	-	-	-0.01 (0.73)	-	-
	DWI NO_FW	0.83	107461	0.01 (0.08)	-	-	-	-0.01 (0.75)	-	-
	DWS FW	0.88	90726	0.01 (0.82)	-	-	-	-0.01 (0.06)	-	-
	DWS NO_FW	0.85	79967	0.01 (0.77)	-	-	-	-0.01 (0.08)	-	-
Sulfate	DEM FW	0.60	76656	-0.01 (0.12)	-	-	-	-0.01 (0.48)	-	-
	DEM NO_FW	0.56	56580	-	0.01 (0.56)	-	-	-	-	-
	DWI FW	0.58	56926	-	0.01 (0.33)	-	-	-	-	0.01 (0.25)
	DWI NO_FW	0.42	100260	-	0.01 (0.42)	-	-	-	-	-
	DWS FW	0.58	74998	-0.01 (0.15)	-	-	-	-0.01 (0.43)	-	-
	DWS NO_FW	0.50	68961	-	0.01 (0.50)	-	-	-	-	-
Specific Conductance	DEM FW	0.85	6040	0.01 (0.17)	-	-	-	-0.01 (0.68)	-	-
	DEM NO_FW	0.82	4834	-	-	-	-	-0.01 (0.65)	-	-0.01 (0.17)
	DWI FW	0.84	3838	-	-	-	-	-0.01 (0.84)	-	-
	DWI NO_FW	0.86	2554	-	-	-0.03 (0.04)	-	-0.01 (0.82	-	-
	DWS FW	0.86	5144	0.01 (0.13)	-	-	-	-0.01 (0.73)	-	-
	DWS NO_FW	0.82	5078	0.01 (0.12)	-	-	-	-0.01 (0.70)	-	-
pH	DEM FW	0.82	4.18	0.06 (0.71)	0.03 (0.12)	-	-	-	-	-
	DEM NO_FW	0.84	3.56	0.05 (0.72)	0.03 (0.12)	-	-	-	-	-
	DWI FW	0.85	3.58	0.06 (0.72)	0.04 (0.13)	-	-	-	-	-
	DWI NO_FW	0.84	3.85	-	-	-	-	-0.04 (0.67)	-	-0.03 (0.17)
	DWS FW	0.90	2.97	0.04 (0.74)	0.06 (0.13)	-	-	-	0.18 (0.03)	-
	DWS NO_FW	0.87	2.78	0.06 (0.75	0.03 (0.13)	-	-	-	-	-

Table 10. 1995-TM regression models. Calcium, magnesium, chloride, and sulfate concentrations were expressed in microequivalents per liter for model development.

CCAP Table Title

Parameter	Model Type	Model R^2	PRESS	Intercept	Coefficients				
					Developed Land	Upland Agriculture	Wetland Agriculture	Upland Forest	Wetlands
Calcium	DEM	0.90	56190	3.17	-	-	-	-0.02	-0.01
	DWI	0.76	74301	2.24	-	0.02	-	-0.01	-
	DWS	0.87	58399	3.20	-	-	-	-0.02	-0.01
Magnesium	DEM	0.89	37785	1.52	0.01	0.02	-	-	-
	DWI	0.78	56258	1.58	0.01	0.02	-	-	-
	DWS	0.86	39720	1.55	0.01	0.02	-	-	-
Chloride	DEM	0.88	86172	2.06	0.01	0.00	-	-	-
	DWI	0.75	495039	2.11	0.01	0.01	-	-	-
	DWS	0.85	102919	2.37	0.01	-	-	0.00	-
Sulfate	DEM	0.51	70233	1.96	-	0.01	-	-	-
	DWI	0.42	100095	1.97	-	0.01	-	-	-
	DWS	0.47	80483	1.97	-	0.01	-	-	-
Specific Conductance	DEM	0.83	6731	1.60	0.01	0.01	-	-	-
	DWI	0.74	7178	2.38	-	-	-	-0.01	-0.01
	DWS	0.81	7675	1.61	0.01	0.01	-	-	-
pH	DEM	0.86	3.93	4.30	0.05	0.03	-	-	-
	DWI	0.85	4.59	8.99	-	-	-	-0.06	-0.04
	DWS	0.90	3.07	4.35	0.05	0.03	-	-	-

Table 11. Stream-vegetation regression-models for the 1995 ITUM land-use data sets. R-square values are shown in parentheses.

All land-uses included in the analysis.

Model Type	Model R^2	PRESS	Intercept	Coefficients						
				Developed Land	Upland Agriculture	Wetland Agriculture	Barren Lands	Upland Forest	Water	Wetlands
1995 DEM	0.68	107904	12.44	4.28 (0.05)	3.68 (0.57)	12.20 (0.06)	-	-	-	-
1995 DWI	0.56	136354	48.29	-	8.19 (0.56)	-	-	-	-	-
1995 DWS	0.61	122174	51.13	-	6.10 (0.61)	-	-	-	-	-

Only developed land, upland agriculture, and barren land included in the analysis.

Model Type	Model R^2	PRESS	Intercept	Coefficients						
				Developed Land	Upland Agriculture	Wetland Agriculture	Barren Lands	Upland Forest	Water	Wetlands
1995 DEM	0.65		404.47	-	-	-	-	-3.61 (0.33)	-	-4.12 (0.32)
1995 DWI	0.58		572.14	-	-	-	-	-5.67 (0.24)	-	-5.15 (0.34)
1995 DWS	0.66		447.11	-	-	-	-	-4.12 (0.35)	-	-4.35 (0.30)

Table 12. Stream-vegetation model-validation results for the 1995 ITUM land-use data sets.

Model Types	N	p-level
1995 DEM & 1995 DWI	34	0.925
1995 DEM & 1995 DWS	34	0.638
1995 DWI & 1995 DWS	34	0.694

Summary statistics for the residuals of each model.

Model Type	N	Mean	Median	Minimum	Maximum	Lower Quartile	Upper Quartile	Quartile Range	Std.Dev.
1995 DEM	34	51.7	34.9	1.8	349.8	17.8	57.6	39.8	66.8
1995 DWI	34	49.5	32.5	1.1	209.4	15.7	76.1	60.4	46.8
1995 DWS	34	53.2	38.7	4.9	197.4	18.1	64.1	46.0	45.4

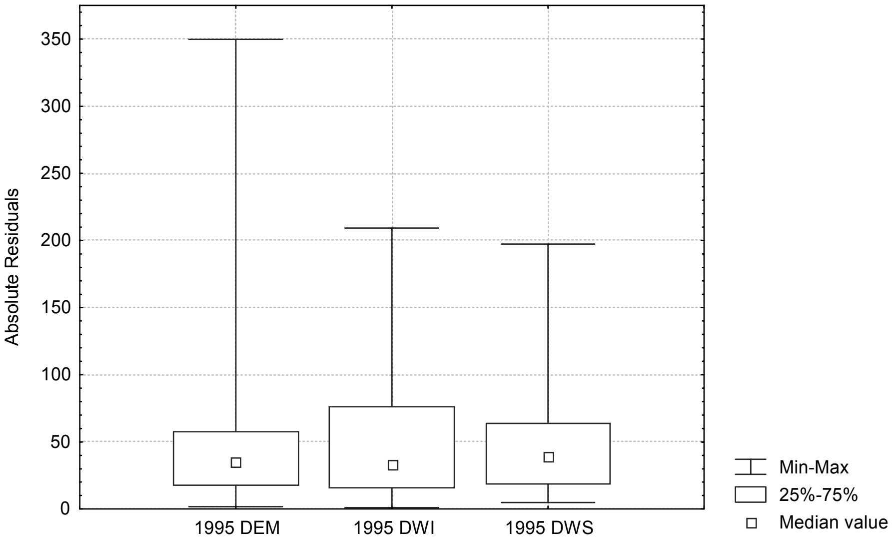

Figure 11. Comparison of absolute residuals from 1995 ITUM land-use/stream-vegetation model-validation analyses.

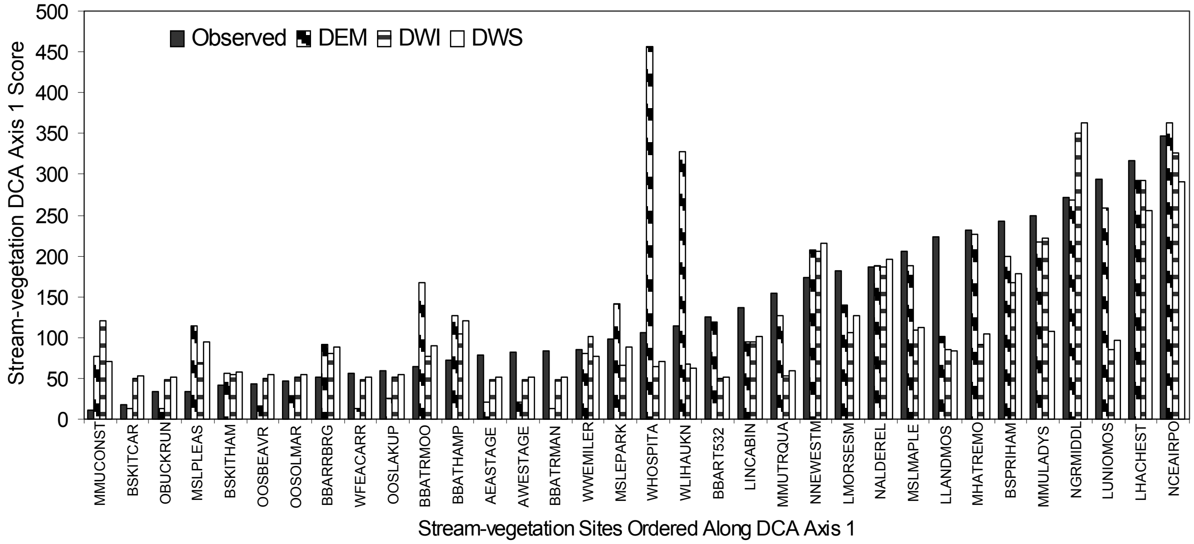

Figure 12. Comparison of observed and predicted stream-vegetation site scores from the 1995 ITUM land-use/stream-vegetation model-validation analyses.

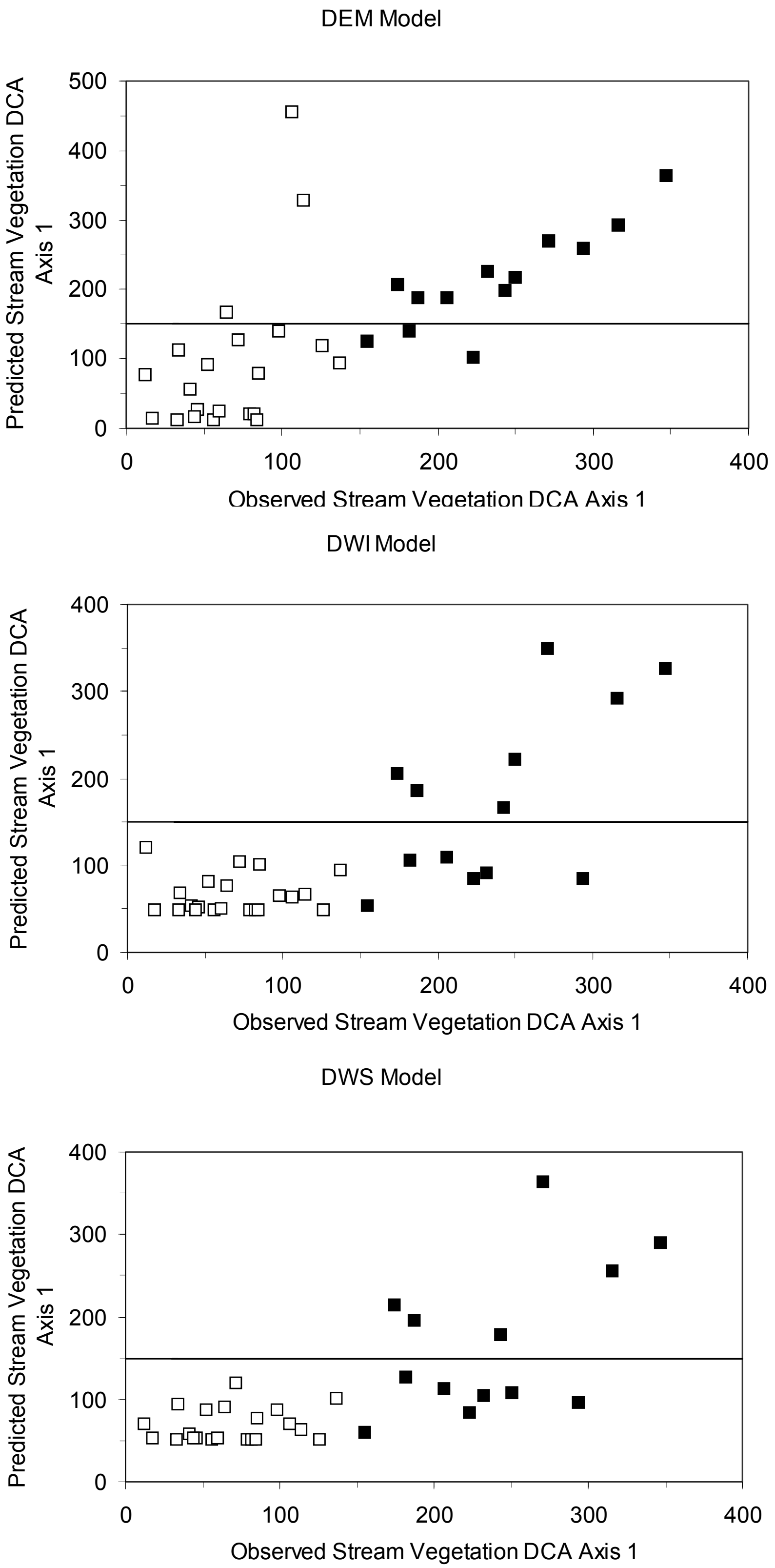

Figure 13. Scatter plots of observed versus predicted stream-vegetation site scores from the 1995 ITUM land-use/stream-vegetation model-validation analyses. Sites with DCA axis 1 scores greater than 150 were characterized by a high percentage of non-Pinelnds plant species.

Table 13. Stream-fish multiple-regression model results for the 1995 ITUM land-use data sets. R-square values are shown in parentheses.

All land-uses included in the analysis.

Model Type	Model R^2	PRESS	Intercept	Coefficients and R-square Values						
				Developed Land	Upland Agriculture	Wetland Agriculture	Barren Lands	Upland Forest	Water	Wetlands
1995 DEM	0.69	13159	15.37	1.24 (0.13)	1.57 (0.56)	-	-	-	-	-
1995 DWI	0.74	11495	14.46	1.63 (0.17)	2.32 (0.57)	-	-	-	-	-
1995 DWS	0.71	13067	15.58	1.43 (0.15)	1.68 (0.56)	-	-	-	-	-

Only upland forest, water, and wetlands included in the analysis.

Model Type	Model R^2	PRESS	Intercept	Coefficients and R-square Values						
				Developed Land	Upland Agriculture	Wetland Agriculture	Barren Lands	Upland Forest	Water	Wetlands
1995 DEM	0.70		154.72	-	-	-	-	-1.23 (0.39)	-	-1.94 (0.31)
1995 DWI	0.73		221.39	-	-	-	-	-1.94 (0.33)	-2.59 (0.07)	-2.31 (0.33)
1995 DWS	0.75		171.64	-	-	-	-	-1.35 (0.39)	-	-2.16 (0.36)

Table 14. Stream-fish model-validation results for the 1995 ITUM land-use data sets. Asterisks denote the tests significant after the Bonferonni correction.

Model Types	N	p-level
1995 DEM & 1995 DWI	26	0.012*
1995 DEM & 1995 DWS	26	0.028
1995 DWI & 1995 DWS	26	0.534

Summary statistics for the residuals of each model.

Model Type	N	Mean	Median	Minimum	Maximum	Lower Quartile	Upper Quartile	Quartile Range	Std.Dev.
1995 DEM	26	12.7	7.2	2.2	45.0	4.7	15.6	11.0	11.5
1995 DWI	26	15.2	12.2	0.6	46.3	6.1	20.9	14.8	12.3
1995 DWS	26	13.3	7.8	0.4	43.3	4.7	15.6	10.9	11.9

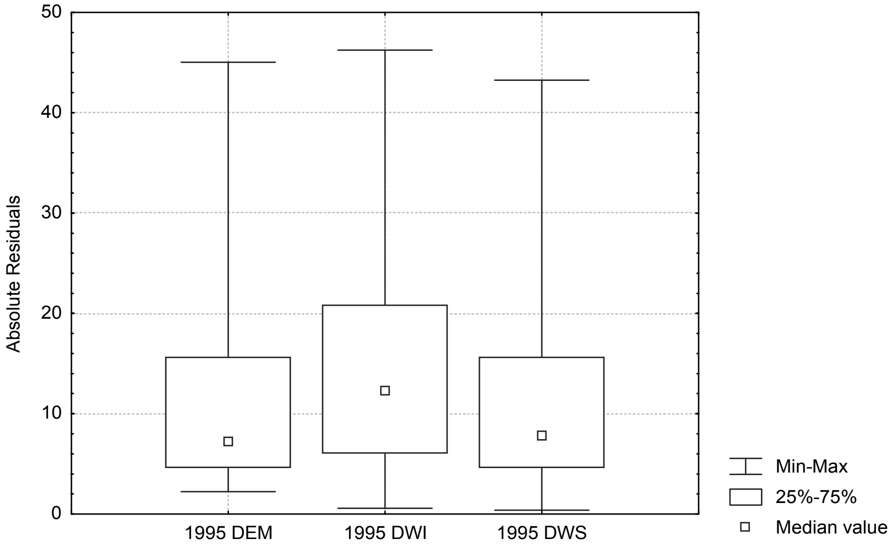

Figure 14. Comparison of residuals from the 1995 ITUM land-use/stream-fish model-validation analyses.

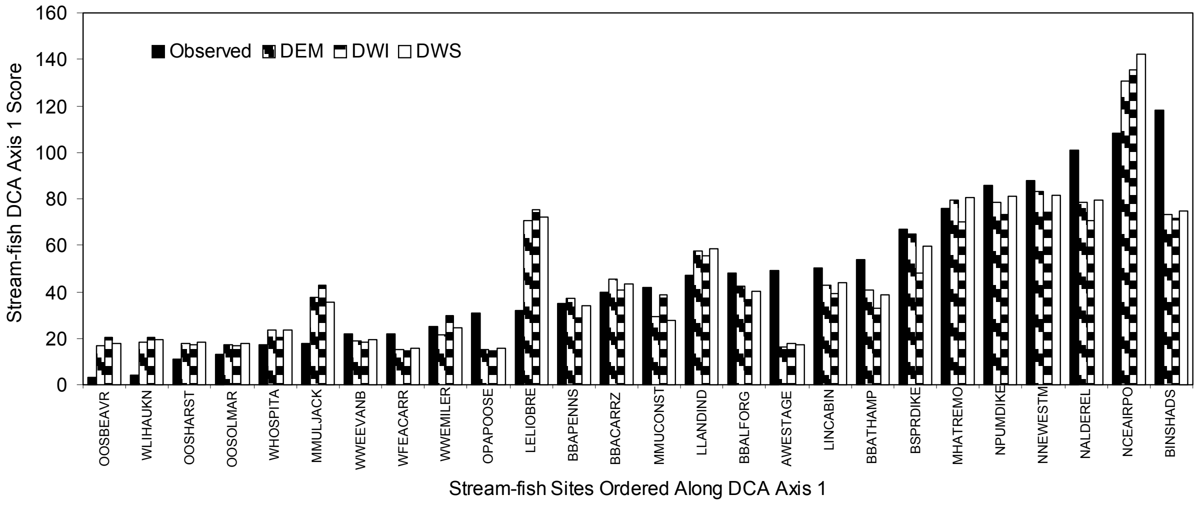

Figure 15. Comparison of observed and predicted stream-fish site scores for the 1995 ITUM land-use/stream-fish model-validation analyses.

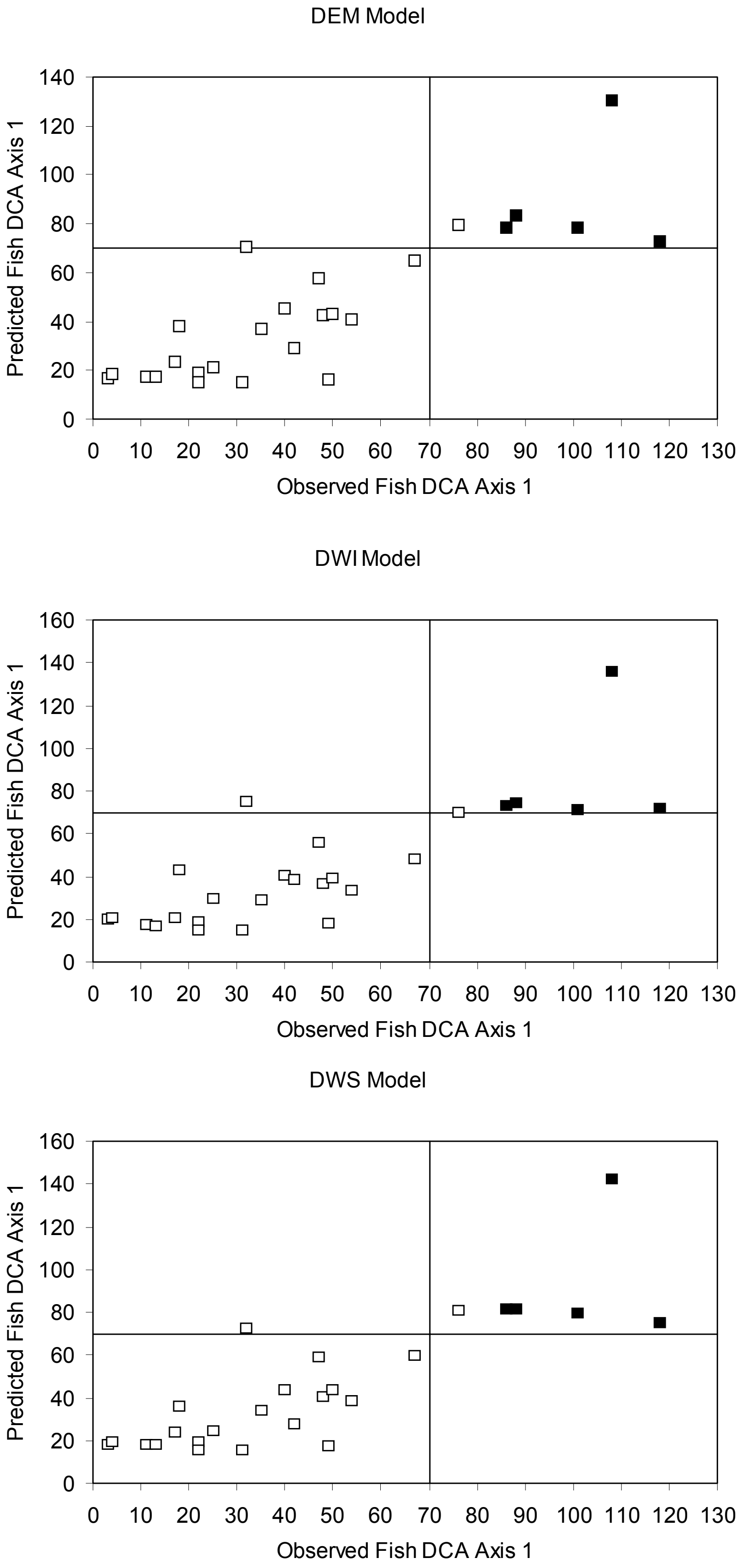

Figure 16. Scatter plots of observed versus predicted stream-fish site scores from the 1995 ITUM land-use/stream-fish model-validation analyses. Sites with DCA axis 1 scores greater than 70 were characterized by a high percentage of non-Pinelands fish species.