

4.0 Cumulative Impacts to the Peace River Watershed

An analysis of the cumulative impacts to the Peace River watershed requires a comparison of land uses, hydrology, and water quality among individual basins in the watershed. To accomplish this, historic changes and patterns among specific stressors (agriculture, urbanization, mining, and rainfall variability) were examined in the context of hydrology, water quality, and natural habitats for the nine watershed basins. The primary objectives were to differentiate between anthropogenic and natural causes of variability and quantify the relative effects of the anthropogenic stressors and natural variation in rainfall.

4.1 Hydrology

Analysis of impacts to hydrology in the Peace River watershed included rainfall, surface water flows, ground water, and water budget analyses. Trends in the watershed and among basins for each of these indicators are presented in the following sections.

4.1.1 Rainfall

Historical data were analyzed to assess the potential presence of long-term rainfall patterns and evaluate identified patterns and/or seasonal changes in the context of the proposed AMO theory. Conclusions based on the results of the time series rainfall data analyses are summarized below.

- The variability in total monthly rainfall was sufficient to obscure any small changes that may have occurred, and there were no indications of any consistent larger changes (or patterns) when the long-term rainfall data were analyzed on a monthly basis.
- In comparison, when the long-term rainfall data are viewed as annual totals, the data clearly showed both increased variations among the watershed gages and greater indications of both historical wetter and drier intervals. Calculated five-year moving averages indicated relatively longer wet and dry intervals over the period-of-record.
- Long-term annual rainfall averaged indicated rainfall levels were higher prior to the mid-1960s when compared with the period following the mid-1960s.

4.1.2 Wet Season and Dry Season Rainfall

The four-month summer wet season, on average, accounts for approximately 59 percent of the 52 inches of total average annual precipitation. The typical summer wet season is characterized by rainfall patterns that are influenced by frequent localized convective thunderstorms and periodic widespread, heavy rains associated with infrequent tropical cyclones. Over the remainder of the year, rainfall generally occurs as frontal systems moving down and across the area from the northwest. However, high rainfall El Niño events periodically occur during the winter/spring dry months and result in seasonally atypical high flows throughout the watershed. Strong El Niño years are often subsequently followed by La Niña events, which are characterized by much lower

than usual rainfall over extended periods. Summary results of the seasonal analyses of long-term rainfall patterns are presented below.

- Annual average wet season (June-September) rainfall in the Peace River watershed was higher during the 1930s through the mid 1960s when compared with the interval from the late 1960s through the early 1990s.
- No similar long-term patterns were apparent with regard to dry season (January-May and October-December) rainfall.

Monthly rainfall data from the watershed were compared for three AMO periods corresponding with the warmer “wet” phase prior to 1969, the cooler “dry” interval between 1969 and 1994, and the recent warmer “wet” period since 1995. The analyses indicated that during the two warmer AMO phases, rainfall was generally higher at both the beginning and end of the four month summer wet season.

4.1.3 Ground Water Levels

Moving from north to south, the Peace River watershed covers three separate physiographic regions. The northern headwaters region of the Peace River in the Polk Upland province is characterized by numerous lakes and is a regionally significant aquifer recharge area. The physiography of the upper Peace River basin then transitions from this upland, internally drained lake district to a poorly drained upland region extending approximately from Bartow south into central Hardee County. Flowing south, the Peace River then passes through both the DeSoto Plain and the Gulf Coastal Lowlands. The underlying geology of the Peace River watershed includes three primary aquifer systems.

- The upper surficial aquifer system, the thickness of which extends over tens of feet, primarily includes Holocene to Pliocene age unconsolidated quartz sand, silt, and siliciclastic sediments.
- The intermediate aquifer system lies between the surficial and Upper Floridan aquifers and is comprised of thin, often discontinuous layers of limestone, dolomite, gravel, sandstone, or sand imbedded in thick phosphatic clays. Thickness of the intermediate aquifer ranges from less than 100 feet north of Lake Hancock and dips and thickens south across the watershed to more than 600 feet in Charlotte County. Permeable zones (PZ) of the intermediate aquifer vary in permeability, confinement, and composition. The uppermost producing zone, PZ 1, is used almost entirely for domestic supply. The second zone, PZ 2, has low permeability and functions hydrologically as a localized aquifer. The third zone, PZ 3, is more permeable than the upper zones and appears to have a moderate to good hydraulic connection with the Floridan aquifer. Large head differences between the surficial aquifer and the Upper Floridan aquifer indicate relatively low hydraulic connection and tight confinement in most of the watershed. An exception is the unique karst formations along the river bed of the upper watershed between Bartow and Homeland which connect the river with deeper underlying layers.

- Structurally, the Upper Floridan aquifer system is comprised of Eocene/Paleocene Suwannee and Ocala limestone formations, as well as portions of the dolomite Avon Park formation. The Upper Floridan aquifer system underlying the Peace River watershed is generally comprised of a pair of permeable zones separated by semi-confining, low permeable, limestone. Water within the Upper Floridan aquifer generally becomes more mineralized as the depth of the system increases towards the southwest moving along the river south from the top of the watershed.

District studies have provided comprehensive overviews of available historical information and changes in ground water levels in the upper Peace River watershed, as well as the associated impacts of historical ground water withdrawals.

- Historically, surficial and intermediate aquifer ground water level data from the late 1970s (ROMP 59, 45, and 40) generally indicate that aquifer levels in the upper watershed have not progressively changed over the last 20 years.
- Predevelopment Upper Floridan aquifer levels were an estimated 11 to 23 feet higher than the 1948 to 1960 average at SWFWMD ROMP wells 60, 59, and 45 located near Bartow and Ft Meade. Water levels then markedly declined and reached historical low levels in the mid 1970s. However, Upper Floridan aquifer levels in the upper watershed increased by approximately 20 feet during the subsequent several decades.
- These observed dramatic declines in Upper Floridan aquifer water levels following 1960 essentially eliminated ground water discharges (base flows) to the upper Peace River from Kissengen and other spring formations in the upper watershed.

As part of the Peace River Cumulative Impact Study, USGS and District ground water level information were combined from matching locations. The intent was to obtain historical, long-term data from routine standardized monitoring programs with documented quality assurance protocols to avoid potential data discrepancies. Data were then subset based on the number of observations and the length of record available from each monitoring location. Using these criteria, 51 currently active monitoring wells with data dating back at least into the 1980s were selected and time series plots were developed over the period-of-record for each location. Long-term ground water patterns indicated by the time series plots of ground water level presented by region (county) and aquifer, are summarized below.

- **Polk County** – Unlike the southern areas of the watershed, the periods-of-record for many of the monitoring wells in this region of the Peace River watershed extend back to the early 1960s and even the mid 1950s. No patterns of decline or increase are apparent in most of the monitoring wells with shorter records (ROMP wells 45, 57, and 59). However, long-term lower intermediate (PZ 3) and Floridan monitoring well levels (Fort Green Springs and ROMP 60) generally indicate historic declines through the late 1960s and early 1970s followed by increases in water levels. Exceptions to these patterns are apparent in long-term Floridan aquifer levels at both Loughman Deep and ROMP 40 locations, where levels have declined since the early 1980s. The influence of the recent

1999-2001 drought is apparent at many of the long-term monitoring sites in the upper watershed.

- **Hardee County** – Lower Intermediate (PZ 3) and Floridan ground water levels at ROMP 30, and Floridan levels at ROMP 31, exhibit relatively large (10-25 feet) short term variations, and general patterns of declining water levels dating back to the beginning of monitoring at the end of the 1970s / early 1980s. Lower (PZ 3) Intermediate ground water level data at the Rowell Deep monitoring site date back to the 1960s and patterns indicate a long-term decline in water levels over the period-of-record.
- **DeSoto County** – Lower Intermediate (PZ 3) and Upper Floridan ground water level data from the Marshal Deep monitoring location indicate a long-term decline in water levels since the early 1960s. Smaller declines appear to date back to the 1970s and are evident from intermediate and Floridan data at ROMP 31. Aquifer levels at the other wells in the region have remained relatively stable over their periods-of-record, although influences of the 1999-2001 drought are apparent at several wells.
- **Charlotte County** – Ground water level data from the long-term monitoring sites in the southern portion of the Peace River watershed date back only to the 1970s and are limited to surficial and intermediate aquifer measurements. Levels at ROMP 11 (intermediate) appear to have undergone sudden declines not apparent at the other regional monitoring sites.

These comparisons indicate that the aquifer levels in recent decades have declined the most in the central and southern portions of the watershed. In contrast, ground water withdrawals for mining operations have been dramatically reduced since the 1970s due to conservation and capture of site stormwater, which has led to a recovery of ground water levels in Polk County. However, much of the reduced use by phosphate mining has been offset by increases in use in the basin for potable and agricultural purposes.

4.1.4 Surface Water Flows

Wetlands drained by ditching and canal construction for agriculture and/or urban development can decrease surface water storage and increase surface water conveyance in the watershed, resulting in a decline in shallow water table elevations. In addition, phosphate mining, as well as aspects of the reclamation of mined lands, can affect surface water and runoff, storage, aquifer recharge, and evapotranspiration. The expansions of more intense agriculture, urbanization, and phosphate mining in the Peace River watershed have affected both surface water runoff and infiltration rates. Extensive areas of the Peace River at Bartow, Peace River at Zolfo Springs, and Payne Creek basins have been altered by phosphate mining activities. Ground water withdrawals have lowered the potentiometric surface of the Upper Floridan aquifer allowing the river to flow into sink holes, thus reversing base flow contributions from these aquifers. The early loss of base flows in the upper reaches of the Peace River in Polk County reflected historic ground water reductions predominantly associated with mining withdrawals from the Upper Floridan aquifer

system. The cessation of spring flows in the upper watershed was subsequently compounded by loss of flows from the riverbed via sinkholes and seepage to the underlying aquifer.

The more southern Peace River watershed basins have also experienced extensive land use and hydrologic alterations that are reflected in the cumulative loss of wetland and native upland habitats as agriculture in the southern basins progressively changed from predominately unimproved pasture to improved pasture, and then to increasing areas of more intense farming such as citrus and row crops. These progressions towards more intense agricultural land uses were associated with commensurate increases in ground water use.

4.1.5 Long-term Changes in Watershed Flows

Nonparametric Seasonal Kendall Tau tests were conducted for the USGS watershed flow gages to determine the presence of statistically significant trends over time. The results are summarized below.

- Low, median, and higher flows at the three Peace River gages in the main channel (Bartow, Zolfo Springs, and Arcadia) show significant declines over longer time intervals beginning in the 30s, 40s and 50s. However, there have not been any statistically significant changes in the tested flow percentiles since 1970 (35 years) in the main stem of the river.
- The long-term patterns of declines at these three Peace River gages are very similar to historic flow patterns identified at the reference basin Withlacoochee River at Croom gage.
- In the southern portion of the watershed, by comparison, flows have increased over their periods-of-record. Shell Creek flow data indicate statistically significant increases in the lowest flow percentiles (base flows), while there have been increasing trends in Prairie Creek at all percentiles between the monthly minimum and median values, and all but the very highest percentiles of flow at the Joshua Creek gage have increased over time.
- The increased flows in the southern basins are similar to those observed outside the Peace River watershed at both the Myakka River near Sarasota and Little Manatee River near Wimauma gages, both of which have historically experienced anthropogenically augmented flows.

4.1.6 Atlantic Multidecadal Oscillation

Graphical and statistical methods of analysis were used to evaluate the influence of AMO events on patterns of higher flows that occurred during the 1930-1960 time interval, the declines in flows during the 1960s and early 1970s, and the subsequent signs of increasing flows since the mid 1990s.

- Annual rainfall during the 1936–1965 thirty-year period was higher when compared with the subsequent 1966–1995 period.

- Summer wet season (June-September) flows were distinctly higher for the high (Q10), mean and median (Q50) percentiles during the two warmer “wet” AMO periods when compared to the cooler “dry” 1969-1994 phase.
- There were no large consistent differences among the three AMO periods for the other eight months of the year.
- Differences among the three AMO periods were also not apparent in low (Q90) monthly summer flows.
- Plots of cumulative annual flow versus cumulative annual rainfall (double mass) indicate distinct changes in the relationships between rainfall and flow following two “breaks”, one in the early 1960s and the other in the 1990s.
- These breaks in the relationships between cumulative long-term river flow and rainfall generally coincide with the proposed AMO wet and dry southwest Florida rainfall periods.
- The breaks in the graphics of both the cumulative flows over time, and cumulative flow versus cumulative rainfall for the Charlie Creek and Withlacoochee River at Croom basins were very similar to those observed for the Peace River gages.
- Most of the variation in annual total flow at the Peace River at Arcadia gage coincides with similar long-term changes at the reference Withlacoochee River at Croom USGS gaging station. This suggests that most of the variation in total annual flow at these gages is due to natural long-term variations in rainfall in southwest Florida. As previously described, the Withlacoochee River at Croom gaging station was selected for comparison because it is north of the Peace River watershed and outside the influence of the major spring flows that occur farther downstream, and it is also outside the influence of phosphate mining and extensive intense agriculture and urban development.
- Similarly, most of the long-term variations in total annual flow observed at the Peace River at Zolfo Springs USGS gaging site were very similar to similar variation at the Withlacoochee River at Croom.
- In contrast, comparisons of annual total cumulative flows at the Peace River at Bartow and the Withlacoochee River at Croom indicate breaks in the flow relationships around 1963 and again around 1990. The timing of these apparent “breaks” does not coincide with any apparent large scale anthropogenic changes in the Peace River at Bartow basin that could account for the change in annual total flows. However, these two changes in flow relationships do coincide roughly with the hypothesized changes in AMO oscillation. The changes between the two basins may reflect differences in rainfall/flow interactions between basins with and without substantial impacted natural base flow.

4.1.7 Water Budget

The water budgets are useful for understanding the magnitude of, and relationships among, the water fluxes in the Peace River watershed and are best used in conjunction with time series data to identify and assess trends that are of interest. For example, changes in rainfall or stream flow over time that may be easily recognizable in a time series representation may be difficult to see based on water budget results alone. Inter-annual variability in a major water budget parameter, such as rainfall, is often greater than potential significant long-term changes. Therefore, when assessing cumulative hydrologic impacts, it is best to initially identify trends and then assess the impact of such trends on watershed functions using water budgets.

Water budgets can be used to quantify the relative hydrologic impacts of natural and anthropogenic changes. However, anthropogenic activities must be of sufficient magnitude to differentiate anthropogenic impacts from the natural variations, or “noise” in the data. Consequently, only relatively large anthropogenic effects are apparent from the water budgets developed for the Peace River watershed and these analyses may better characterize hydrologic responses among basins at the watershed level, but be inappropriate for assessing small basin- or site- specific conditions. As such, the water budget results should be interpreted with some degree of caution. The water budgets were based on simplified conceptual models of watershed functions intended to account for water fluxes at an order of magnitude scale. The water budget results are based on many parameters with a large amount of uncertainty, and anthropogenic effects were often dwarfed by the variation in natural hydrologic functions such as rainfall and evapotranspiration.

Water budgets were prepared for eight basins in the Peace River watershed, for four representative time periods relative to available land use information: 1941-1943, 1976-1978, 1989-1991, and 1997-1999. The Lower Coastal Peace basin was excluded due to the absence of a gage in that basin. The goal of the water budget analysis was to quantify the volumetric flow rates of water in and out of each basin, and to the extent possible, assess the cumulative impacts over time.

- Rainfall was the largest component of the water budgets, and natural variation in rainfall rates was the most important factor in explaining the change in water budgets over time.
- Compared to the “early development” period of 1941-1943, rainfall declined in 1976-1979 and 1989-1991, but recovered during the 1997-1999 period.
- Corresponding to these long-term rainfall patterns, stream flow was lowest in the 1976-1979 and 1989-1991 periods, and increased again during the 1997-1999 period. When expressed per unit basin area (converted to inches per year), stream flow is the lowest in the basin above the Bartow gage, and the highest in the Payne Creek and Joshua Creek basins.
- After rainfall, evapotranspiration (ET) was the second largest component of the water budgets, with average ET being on the order of 37 inches per year.

- The impact of land use changes on ET was assessed via land use/land cover specific “crop coefficients”.
- The water budget analysis indicates that the impact of land use changes on ET has been relatively small. Area-weighted crop coefficients have decreased in the upper portion of the Peace River basin (above Zolfo Springs), but have remained stable elsewhere in the basin.
- The decline in crop coefficients and ET in the upper portion of the basin can be attributed to increased urban development. The estimated ET reduction in the watershed above Bartow from the early development period of 1941-1943 to the most recent assessment period of 1997-1999 was approximately three inches/year.
- While rainfall is the most important component of the water budget and the primary influence on mean stream flows, the subtle influence of human activities often manifests itself via the runoff and base flow components of stream flow at the basin level.
- Examples of human influences that are recognizable in the water budget analysis include:
 - Reduced base flow in the upper Peace River has occurred as the combined result of declining potentiometric surfaces in Upper Floridan aquifer, the loss of storage due to declining lake levels in Saddle Creek and Peace Creek drainages, and increases in urbanization and associated increased runoff.
 - In contrast there have been increases in base flow in the tributary basins affected by agriculture. Stream base flow in Joshua Creek has approximately doubled since the late 1970s. Such increases can be attributed to agricultural irrigation being returned as stream flow that essentially represents a transfer from ground water to surface water. Irrigation water use is greatest during the dry winter and spring months, and thus augments natural base flow.
 - Increases in stream flow and base flow have also occurred in Payne Creek, which has undergone extensive phosphate mining. The exact hydrologic impacts and causal relationships from phosphate mining were difficult to assess at the scale of this water budget analysis, but stream flow data indicate that Payne Creek has higher standardized stream flows and base flow than other basins in the Peace River watershed. Ground water discharges associated with mining activities and agriculture are likely contributing factors to increases in stream flow.
- Hydrologic modeling using the EPA Stormwater Management Model (SWMM) was used to further analyze the relationship between land use change and runoff. Three scenarios were evaluated:
 - Urban land uses remained native uplands
 - Active phosphate mining areas remained native uplands
 - Wetlands not drained and converted into improved pasture

- The SWMM runoff analysis suggested the following:
 - Urbanization has had the largest impact on runoff in the basin above Bartow and had a runoff value that was 23 percent higher than if currently urbanized areas were native uplands. Impacts in other basins (less urbanized) were much smaller.
 - Without phosphate mining, runoff would be 10 percent higher in Payne Creek.
 - Conversion of wetlands to improved pasture has affected both dry season and wet season runoff. In the dry season, wetlands act as storage areas, and the conversion to improved pasture increased runoff by up to 5 percent. During wet weather, the presence of wetlands would have increased runoff rates by about 11 percent.

4.2 Water Quality

Historically, water quality in the upper Peace River watershed has been affected by a number of anthropogenic activities. These have included point and older nonpoint source discharges from phosphate mining and processing, point source municipal/industrial effluents, and nonpoint runoff from both expanding urban and intense agricultural land uses. The two primary influences on water quality in the Peace River watershed have historically been attributed to: 1) nutrient inputs and the eutrophication of Lake Hancock and subsequent increased nitrogen loadings to the upper river; and 2) discharges to the river from phosphate mining and processing associated with extensive mining of large tracts of land in the upper basins. Designated water bodies currently listed as impaired by FDEP are mapped in Figure 4.1 and identified by Water Body Identification (WBID) number. These impaired water bodies are more common in the urbanized northern and southern portions of the watershed.

More recently, increases in ground water discharges from agricultural practices in the southern basins have resulted in increases in both conductivity and associated water quality characteristics, and nitrogen levels. Over the past several decades, agricultural land uses in many areas of the Peace River watershed have undergone marked conversions from unimproved grazing pasture to improved pasture and increasingly to citrus and row crops. Some of the largest conversions to more intense agricultural uses have occurred in the southern basins and have been associated with increased discharges of highly mineralized ground water and nonpoint source nutrient loadings (nitrogen).

4.2.1 Time Series Comparisons of Water Quality among Basins

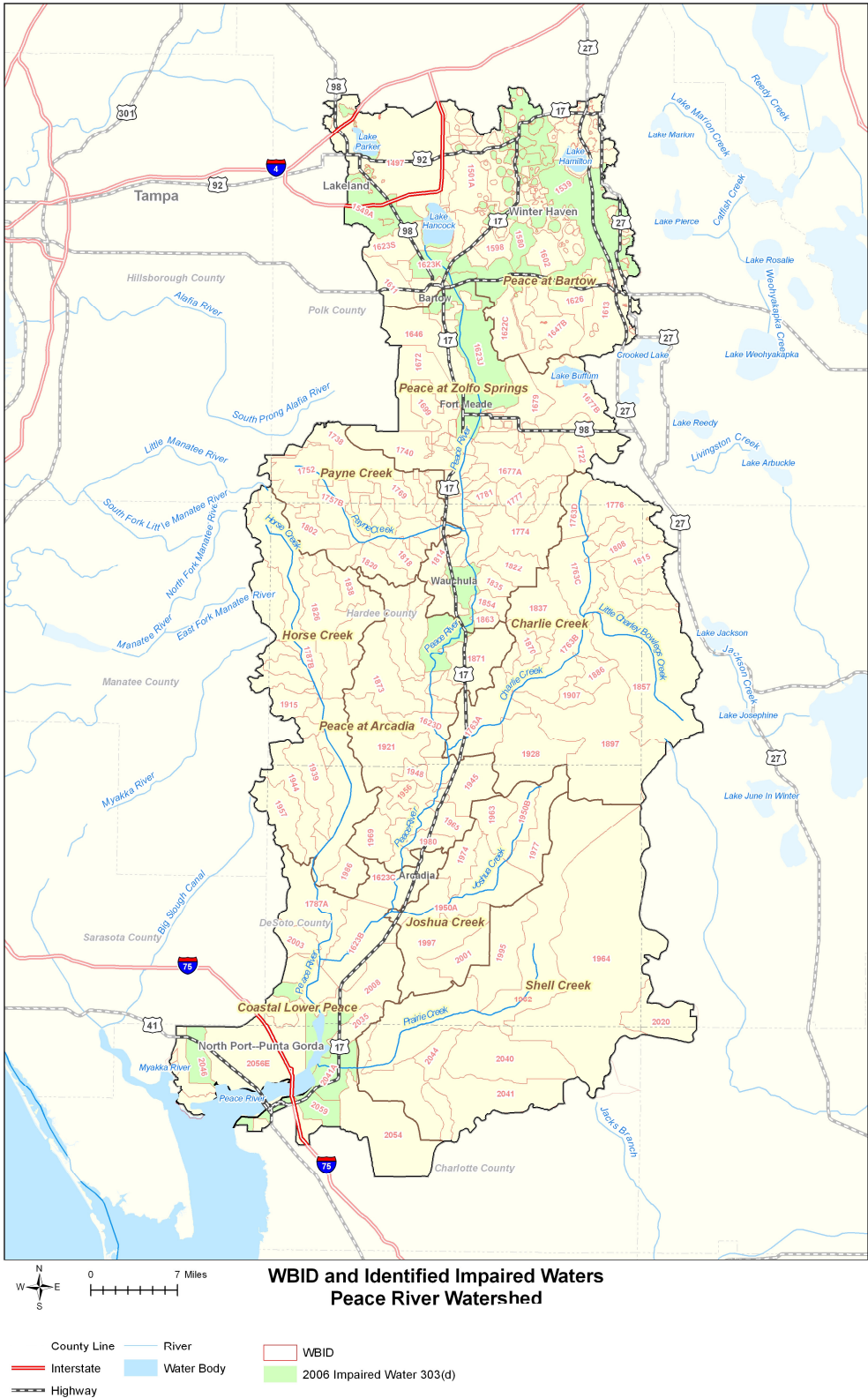
The following briefly describes some of the major water quality patterns apparent in the time series information.

- Lake Hancock water quality has been characterized as “poor”, based on the Florida Trophic State Index, since at least 1970, and water quality in the lake has been a concern as far back as the 1950s. The FDEP has verified the impaired condition of the lake and

levels of total nitrogen, total phosphorus, and biological oxygen demand all exceeded the State threshold screening values by considerable amounts.

- A large portion of the organic nitrogen exported from the lake is a result of nitrogen-fixation by high levels of blue green algae concentrations.
- Instances of low dissolved oxygen concentrations are conspicuous in the upstream portions of the Peace River, and both the frequency and downstream extent of low dissolved oxygen levels increase as discharges from Lake Hancock increase. Flows from the lake via Saddle Creek are characteristically high in total suspended solids, total Kjeldahl nitrogen, total organic carbon, and chlorophyll *a*. The high chlorophyll concentrations (algae) and organic material associated with these discharges result in extreme fluctuations in dissolved oxygen levels in the upper Peace River. During periods of high rainfall, discharges from the lake increase, and the low dissolved oxygen conditions are exacerbated.

Figure 4.1. Listed Impaired Water Bodies in the Peace River Watershed (2006)



- Values for a number of other water quality parameters in the upper Peace River have improved noticeably since the 1960s and 1970s following implementation of regulatory measures and changes in phosphate mining practices that reduced the frequency and quantity of discharges. Pre-regulatory direct discharges from the fertilizer manufacturing facilities were also eliminated as a result of regulatory changes, and resulted in decreases in levels of specific conductivity, total dissolved solids, calcium, magnesium, sulfate, silica, total phosphorus, orthophosphate, fluoride, and strontium in the upper river.
- The tributary basins of the Peace River watershed all show water quality changes attributable to mineralized ground water discharges to surface waters from agricultural activities. Depending on the basin (and available data), long-term increases are apparent in conductivity, pH, total dissolved solids, calcium, magnesium, sodium, potassium, chloride, silica, and sulfate. Concentrations of many of these water quality parameters were at or near historical highs during the recent 1999-2001 drought. The basins were ranked relative to the magnitude of the changes in water quality and are listed from largest to smallest changes.
 - Joshua Creek
 - Shell Creek (Prairie Creek and Shell Creek)
 - Horse Creek
 - Payne Creek
 - Charlie Creek
- Water quality impacts in the watershed due to urbanization have historically included discharges from municipal waste water treatment facilities, as well as stormwater discharges. However, many of these discharges have been dramatically reduced/eliminated and water quality has improved due to National Pollutant Discharge Elimination Systems (NPDES) permitting.
- Water in the Upper Floridan aquifer generally is more mineralized moving from the northern region of the Peace River watershed toward the south and west. Consequently, relatively similar volumes of Upper Floridan ground water discharged to receiving surface waters in the southern watershed basins can have a greater effect on surface water quality characteristics when compared to discharges in the northern watershed.
- The high conductivity levels (and other water quality constituents) in these southern agricultural dominated basins directly reflects the discharge of highly mineralized Upper Floridan ground water into these creeks.
- Water quality in a number of the tributary watershed basins that have undergone land use changes to more intense agriculture also show recent increases in inorganic nitrite+nitrate nitrogen concentrations.

- Dissolved inorganic phosphorus concentrations in the lower Peace River/upper Charlotte Harbor estuary are extremely high when compared to other estuarine systems. However, measured phosphorus levels in the estuary have declined by as much as an order of magnitude since the early 1980s.
- Except for statistically significant long-term declines in phosphorus levels and recent significant increases in silica concentrations, the water quality of the lower Peace River and upper Charlotte Harbor has remain relatively unchanged over the past quarter century.
- There are, however, distinct seasonal differences in a number of water quality characteristics in the lower river and estuary (including salinity, dissolved oxygen, water color, turbidity, phosphorus, nitrogen, organic carbon, and chlorophyll *a*) related to differences in flow and/or temperature.
- Phytoplankton levels in the Peace River and Charlotte Harbor during periods of low to moderate freshwater flow are limited by the availability of inorganic nitrogen. However, as flows increase, water color levels correspondingly increase and phytoplankton production in the river and upper harbor are increasingly limited by the ability of light to penetrate the water column.
- Dissolved oxygen concentrations in the lower Peace River/upper Charlotte Harbor estuary show clear seasonal cycles in response to higher freshwater flows during the summer wet season. The duration and magnitude of periods of low dissolved oxygen concentrations increase toward the river mouth and harbor as higher bottom salinities establish greater vertical stratification in the water column during high flows. Bottom dissolved oxygen concentrations in upper Charlotte Harbor are characterized by hypoxic (less than 2.0 mg/L) and even anoxic (less than 0.2 mg/L) conditions during extended periods of high flows during the summer wet season.

4.2.2 Water Quality Comparisons among Basins

Another objective of this study was to compare and contrast current water quality characteristics among and between watershed basins and assess potential causes or explanations for observed differences. Two recent sequential time periods provided the opportunity to evaluate selected water quality parameters under extremely dry and wet conditions. Both surface water flows and ground water demands were strongly influenced by the La Niña three-year drought that affected the Peace River watershed from 1999-2001. The three years that followed (2002-2004) were characterized by wetter than normal conditions, during which a number of tropical cyclonic events influenced the Peace River watershed. Spatial differences and potential explanations for differences in water quality in the watershed suggest are summarized below. Differences between the extremely dry 1999-2001 and relatively wet 2002-2004 time periods are also presented.

Color – Average levels were distinctly lower in most of the basins during the drier 1999-2001 period when compared with the wetter 2002-2004 period. This reflects the high natural color levels in southwest Florida stream that occur primarily due to humic compounds associated with the runoff of decomposed vegetation and organic material from forested uplands and wetlands. Depending on the source, these humic compounds typically contain high levels of tannins, lignins, and fulvic acids. Water color levels in the Payne Creek basin stand out as characteristically low in comparison with the other basins. This difference was particularly evident during the wetter 2002-2004 interval, suggesting that even during periods of relatively high rainfall, flows are not typically associated with large amounts of decomposed vegetation or organic matter in Payne Creek. Other water quality characteristics, such as conductivity, combined with apparent historic increases in dry season base flow, suggest that Payne Creek flows are often associated with ground water and/or NPDES discharges.

Conductivity (Specific Conductance) – Conductivity levels from 2002 to 2004 at the Joshua, Prairie, and Shell creek monitoring sites were distinctly higher than levels measured in other watershed basins. Mean, median, and maximum conductivity values and the normal range of variation (between the 25th and 75th percentiles) in these three creeks during these most recent wet years were typically more than double the levels observed in other basins. Average conductivity levels throughout the watershed, and particularly at these three creek locations, were generally higher during the preceding dry 1999-2001 period. Conductivity levels at the lower Horse Creek monitoring site near Arcadia were also conspicuously higher during the drought. Large agricultural areas in the lower portion of the Horse Creek basin and in the Joshua and Shell Creek basins have shifted in recent decades to more intensive agriculture that relies heavily on ground water for irrigation and/or freeze protection.

Upper Floridan aquifer ground water generally becomes more mineralized moving from north to south across the Peace River watershed. Consequently, relatively similar volumes of Upper Floridan ground water discharged to receiving surface waters in the southern watershed basins can alter surface water quality much more dramatically when compared to ground water discharged into the more northern basins. The high conductivity levels (and other constituents described below) observed in the southern agricultural dominated basins reflect highly mineralized Upper Floridan ground water being discharged into the creeks.

Ions and Total Dissolved Solids (TDS) – There are a number dissolved positive and negative ions commonly associated with southwest Florida ground water. Data are most widely available for chloride, calcium, sodium, and sulfate ions. The graphical comparisons of these parameters, along with TDS among the watershed surface water monitoring sites again indicates the magnitude of the influences of highly mineralized ground water discharges in the southern agricultural areas, particularly in the Joshua Creek basin. Ion levels in basin surface waters were notably higher the during the 1999-2001 drought than during the ensuing 2002-2004 wetter time interval, as described earlier for conductivity.

Phosphorus and Fluoride – Total phosphorus and orthophosphate values were generally highest in the northern reaches of the main channel of the Peace River. Among the tributaries, the highest concentrations occurred in the Payne Creek basin. Similar spatial patterns were also

reflected for concentrations of fluoride. These elevated concentrations of phosphorus and fluoride are directly associated with areas of historic and current mining.

Dissolved Oxygen (DO) – Comparisons of DO levels among the monitoring locations during the 1999-2001 drought and wetter 2002-2004 periods indicate that DO levels below the Class III standard of 5.0 mg/L, and even reflecting hypoxic conditions (below 2.0 mg/L), occurred primarily in the main river channel between Lake Hancock and Arcadia. Overall, low DO levels are notably lower toward the northern end of the watershed and are more frequent and extend farther down the river during wetter conditions. The reason for these DO patterns is evident in the spatial and temporal patterns of total suspended solids (TSS), turbidity, total Kjeldahl nitrogen (TKN), total organic carbon (TOC), and chlorophyll *a*. These parameters show the high levels of organic materials from Lake Hancock that enter the upper Peace River via Saddle Creek. Discharged water from Lake Hancock has high concentrations of chlorophyll *a* (algae) and organic material that result in extreme fluctuations in DO levels observed in the upper Peace River. During wetter conditions, DO patterns are accentuated by larger discharges from the lake.

Inorganic Nitrite+Nitrate Nitrogen – There are two main sources of inorganic nitrite+nitrate nitrogen in the Peace River watershed. The first is associated with the high levels of organic material from Lake Hancock, while the second more dispersed source is primarily linked with agricultural uses in the tributary basins. The water entering the upper Peace River via Saddle Creek is characterized by very low inorganic nitrite+nitrate nitrogen levels. Most of the inorganic nitrogen in Lake Hancock has been incorporated into algae, resulting in high chlorophyll *a* concentrations. As algae and other organic material are decomposed in the river, organic nitrogen is converted to inorganic nitrogen and downstream concentrations in inorganic nitrogen increase. Relatively high concentrations of inorganic nitrogen are also apparent in a number of the tributary basins with more intense agricultural land uses. Interestingly, relatively high concentrations of inorganic nitrogen were observed in the Payne Creek basin during both the dry 1999-2001 and wetter 2002-2004 time periods.

4.2.3 Conductivity

Increases in conductivity (also known as “specific conductance”) are often linked to an increased influence of water from highly mineralized aquifers on otherwise low-conductivity surface waters. Increased conductivity has been linked to off-site discharge of irrigation waters that originated from the more highly mineralized intermediate and Upper Floridan aquifer. The current water quality standard for specific conductance (Chapter 62-302.530(23)) for Class III waters is the following:

“Specific conductance (micromhos/cm) shall not be increased more than 50 percent above background or to 1275, whichever is greater.”

Based on this standard, the specific conductance water quality standard has been exceeded frequently at a number of locations in Joshua, Prairie, and Shell creeks. While there are only three stream segments (two in Shell Creek and one in Prairie Creek) that have been listed by

FDEP as “verified impaired,” there are additional locations under consideration for listing in the Peace River watershed.

In response to the issue of impairment, SWFWMD developed the “Shell Creek and Prairie Creek Watershed Management Plan”. The goals of this Plan, to be accomplished by 2014, are to reduce specific conductance levels to no more than 775 $\mu\text{mhos/cm}$ at all times, reduce chloride levels to below 250 mg/l, and reduce total dissolved solids (TDS) levels to below 500 mg/l. Thus, the goal of the Reasonable Assurance Plan, which makes up part of the larger Watershed Management Plan, is to reduce conductivity to levels to below the existing state standard “never to exceed” value of 1275 $\mu\text{mhos/cm}$.

Recently, the Triennial Review Committee of FDEP requested the FDEP Biology Section evaluate scientific evidence to evaluate the existing Surface Water Quality Standard for specific conductance and make recommendations for revising standards if necessary. Such a revision, based on available data could result in a more protective standard for biological communities in the Peace River, where data suggest a possible negative impact of increased mineral content of the water on fish populations.

4.2.4 Conductivity and Fish

As part of the Peace River Cumulative Impact Study, fish species reported both from the freshwater and tidal areas of the watershed were compared. This study was based on a review of museum material, as well as information available in the primary and secondary literature. Analyses of available fish species information were conducted using the presence/absence methods, sample based species accumulation estimates, and community based comparisons of similarities among basins.

At virtually all levels examined, from regional to first and second order streams, the existing Peace River fish fauna showed in these previous studies adverse effects over time due to changes believed to be associated with four anthropogenic activities.

- Historic and current landscape changes by agriculture and urbanization
- Historic and current mining for phosphate in streams and other landscape changes
- Historic losses of ground water flows to the river in the upper karst areas of the watershed
- Irrigation runoff from ground water with high total dissolved solids/high conductivity

Many unaltered, low order Peace River watershed streams have very low conductivity levels and acidic pH levels. The State Standard for specific conductivity appears inadequate to protecting many freshwater fishes in Class III waters from adverse impacts.

Many freshwater fishes evolved under conditions of very low levels of total dissolved solids (low conductivity). At least 15 fish species in the Peace River appear to need conductivities less than the present State Standard of 1275 $\mu\text{mhos/cm}$. These species include *Ameiurus nebulosus*, *Ameiurus natalis*, *Clarias batrachus*, *Hemichromis letourneuxi*, *Hoplosternum littorale*, *Notemigonus crysoleucas*, *Dorosoma petenense*, *Fundulus chrysotus*, *Dorosoma cepedianum*,

Amia calva, *Lepomis punctatus*, *Noturus gyrinus*, *Elassoma evergladei*, *Jordanella floridae*, and *Pterygoplichthys* sp. Generalizations regarding fish species and conductivity are presented below.

- Joshua, Prairie and Shell creeks may have experienced significant losses of fish fauna as the result of rising conductivity levels (well above the State Standard) associated with the pumping of highly mineralized ground water.
- Increased conductivity levels in Payne Creek that have resulted primarily from the impacts of mining and agriculture on the landscape may partially explain the occurrence of low numbers of fish species.
- Present day Horse Creek may have more species of fishes than the main stem of the Peace River and certainly more than in the recent past. Phosphate mining is still a minor, but growing component of the Horse Creek watershed. The fish fauna of Charlie Creek may be nearly as rich as Horse Creek, but there is a lack of recent data.

4.3 Land Use

As previously discussed in Chapter 3, land use patterns in the Peace River watershed have changed dramatically since the 1940s. General trends in land uses among basins, both spatially and temporally, are summarized in Table 4.1. In some cases, the patterns of land use that dominate the watershed level are very different from those at the basin level. Basins in the watershed for the purposes of discussion were classified into three general regions:

- Upper watershed - Peace at Bartow, Peace at Zolfo Springs, and Payne Creek
- Middle watershed - Peace at Arcadia and Charlie Creek
- Lower watershed - Horse Creek, Coastal Lower Peace, Joshua Creek, and Shell Creek

Developed and undeveloped land uses (listed below) were quantified for the 1940s, 1979, and 1999 time periods and results are presented in the following sections.

Developed Land Uses

- Improved pasture
- Intense agriculture
- Urban lands
- Mined lands

Undeveloped Land Uses

- Native upland habitat
- Wetlands
- Streams and river channels
- Lakes and open water*

** Lakes may occur as either developed (e.g. mining) or undeveloped land uses*

Developed land uses in the Peace River watershed increased from 12 percent of the watershed in the 1940s to 49 percent in 1979, and grew to 64 percent of the watershed in 1999 (Table 4.2). Changes in undeveloped land uses were commensurate and decreased from 85 percent of the watershed in the 1940s to 48 percent of the watershed in 1979, and 33 percent in 1999. Expansion of agriculture throughout most of the watershed, mining in predominantly three northerly basins, and urbanization in the northern-most and southern-most basins, has resulted in large losses of wetlands and deforestation and/or loss of native upland habitats. There was also a conspicuous increase of nearly 10,000 acres in the lakes and open water land use class between 1940 and 1999. Approximately 6,000 acres of the 10,000 acres were due primarily to mining activities in Peace at Bartow, Zolfo Springs, and Payne Creek basins, and about 1,200 acres were due to increases in agricultural activities in the Shell Creek basin. However, the term “lakes” also includes open water, and cooling ponds for two power facilities in the watershed account for a portion of the lakes.

Table 4.1. Summary of Basin Characteristics and Land Use Changes in the Peace River Watershed

Basin Characteristic		Upper Peace River Watershed			Middle Peace River Watershed		Lower Peace River Watershed			
		Peace at Bartow	Peace at Zolfo Springs	Payne Creek	Charlie Creek	Peace at Arcadia	Horse Creek	Joshua Creek	Shell Creek	Coastal Lower Peace
Current Predominant Land Use		Urban	Mining	Mining	Improved Pasture	Improved Pasture	Improved Pasture	Improved Pasture	Intense Agriculture	Urban
Greatest Land Use Conversion	1940s – 1979	Native upland habitat to pasture and urban	Native uplands to pasture and mining	Native uplands to pasture and intense agriculture	Native uplands to pasture	Native uplands to pasture	Native uplands to pasture	Native uplands to pasture	Native uplands to pasture and intense agriculture	Native uplands to urban and pasture
	1979 - 1999	Native uplands and wetlands to urban and pasture; intense agriculture to urban	Native uplands and pasture to mining	Native uplands to mining	Native uplands to pasture	Native uplands to pasture	Native uplands to pasture	Pasture to intense agriculture	Native uplands to pasture and pasture to intense agriculture	Native uplands to urban and pasture
	1940s - 1999	Native uplands to urban and pasture	Native uplands to pasture and mining	Native uplands and wetlands to mining	Native uplands to pasture and intense agriculture	Native uplands to pasture and intense agriculture	Native uplands to pasture	Native uplands to pasture	Native uplands to pasture and intense agriculture	Native uplands to urban and pasture

Table 4.2 summarizes specific changes in overall land uses at the watershed level between the 1940s baseline period and 1999. Summaries of the land use changes for both developed and undeveloped lands are further compared among the 1940s, 1979, and 1999 time intervals in Figures 4.2 through 4.7.

Table 4.2. Land Use in the Peace River Watershed: 1940s - 1999

Land Use	Acres (Percent) in Land Use Class		
	1940s	1979	1999
Developed			
Improved Pasture	39,640 (2.8)	356,925 (25.6)	379,346 (27.2)
Intense Agriculture	107,115 (7.7)	191,496 (13.7)	229,832 (16.5)
Mined lands	7,495 (0.5)	64,437 (4.6)	143,487 (10.3)
Urban Land Use	14,659 (1.0)	73,049 (5.2)	133,571 (9.6)
Undeveloped			
Native Upland Habitat	834,311 (59.7)	419,449 (30.0)	242,849 (17.4)
Wetlands	354,674 (25.4)	249,255 (17.8)	218,232 (15.6)
Water			
Lakes and open water	33,779 (2.4)	35,432 (2.5)	43,027 (3.1)
Other Water	5,011 (0.4)	6,641 (0.5)	6,338 (0.5)
Total	1,396,683 (100)	1,396,683 (100)	1,396,683 (100)

Table 4.3. Peace River Cumulative Impacts Study: 1940s to 1999*

1940s		1999 Land Use Acres									
Land Use Class	Total Acres	Mined Lands	Urban Land Use	Improved Pasture	Intense Agriculture	Wetlands	Native Upland Habitat	Lakes and Open Water	Bays and Estuaries	Streams and River Channels	Total Acres
Mined lands	7,495	5,230	109	4,725	9,075	35,265	88,351	731	0	1	143,487
Urban Land Use	14,659	621	13,963	7,539	20,257	17,661	73,108	350	63	10	133,571
Improved Pasture	39,640	910	154	14,935	10,710	48,378	304,092	145	0	23	379,346
Intense Agriculture	107,115	276	148	7,657	59,698	14,270	147,710	74	0	0	229,832
Wetlands	354,674	228	69	628	542	200,955	13,048	2,159	5	598	218,232
Native Upland Habitat	834,311	112	187	3,537	6,499	31,042	201,256	124	0	92	242,849
Lakes and Open Water	33,779	117	27	545	320	5,902	5,789	30,181	0	146	43,027
Bays and Estuaries**	692	0	1	0	0	44	7	0	615	3	671
Streams, River Channels**	4,320	0	2	74	14	1,158	951	15	8	3,446	5,668
Total	1,396,683										1,396,683

*The change in land uses between the 1940s and 1999 can first be accounted for by reading across a row. For example, urban lands totaled 14,659 acres in the 1940s and increased to 133,571 acres in 1999 (an increase of 118,912 acres). Urban land uses in 1999 included 621 acres of formerly mined lands, 13,963 acres of urban lands that were urban lands in the 1940s, 7,539 acres of former improved pasture, and 20,257 acres of former intense agriculture. In addition, 17,661 acres of wetlands, 73,108 acres of native upland habitat, 350 acres of lakes/open water, and 10 acres of streams and river channels were converted to urban lands between the 1940s and 1999.

*The difference between the acres of urban lands in the 1940s (14,659) and the acres of urban lands that remained urban lands (13,963 acres) can be accounted for by reading down the urban land use column. For example, 109 acres of urban lands were converted to mined lands, 154 acres of urban lands were converted to improved pasture, 148 acres were converted to intense agriculture, 69 acres were converted to wetlands, 187 acres were converted to native upland habitats, 27 acres were converted to lakes and open water, and 3 acres were converted to bays and estuaries and streams and river channels.

**Streams and river channels are addressed as linear feet of impacts in Table 4.4.

4.3 Loss of Natural Streams and River Channels

Loss of natural stream channels can alter surface water flows and runoff, surface water storage, aquifer recharge, and evapotranspiration, and alter or eliminate fish and wildlife habitat. In the Peace River watershed, these losses are associated with phosphate mining, agriculture, and urban land use activities, which may include channeling, filling, grading, and otherwise altering natural streams. As part of this study, the loss of natural streams in the watershed were quantified and compared between the 1940s and 1999 (Table 4.4). Natural stream segments visible in the 1940s aerial photography but channeled or absent in the 1999 photography were identified as stream losses for this study. The loss of natural stream channels to undeveloped land uses, e.g. lakes, upland habitat, and wetlands also occurred and were likely the result of intermediate land use changes. Similarly, some of the observed losses of stream channels now in urban land use may have also been previously modified. Natural stream channels eliminated during phosphate mining operations may be replaced by ditching, native upland habitats, wetlands, or lakes as a result of subsequent reclamation to another land use.

Stream losses in the Peace River watershed between the 1940s and 1999 totaled 342.7 miles. The largest losses from developed land uses were associated with phosphate mining (101.2 miles), followed by agriculture (64.5 miles), and urban (37.5 miles) land uses. Losses of natural streams were limited primarily to the smaller first and second order streams, rather than the main river channel (third order), although a portion of the Peace River just south of Lake Hancock has been channeled extensively. Importantly, streams already channeled in the 1940s were not identified as losses and, consequently, the loss of stream segments presented here are conservative. In addition, while multiple land use changes may have occurred between the 1940s and 1999, e.g. from agriculture to mining to urban, the most recent land use (1999) associated with the losses in stream segments were assigned to the stream losses and are also presented in Table 4.4. Stream losses are mapped in Figures 4.7 and 4.8.

The greatest loss of natural stream channels occurred in the Lower Coastal Peace basin (77.5 miles), followed by Payne Creek (66.9 miles), Peace River at Bartow (57.8 miles), and Peace River at Zolfo Springs (49.4 miles). Phosphate mining was the largest single 1999 land use that occurred in the place of former natural stream channels, and accounted for 105.2 miles (29.5 percent) of the absent or channeled stream segments. Phosphate mining accounted for 82 percent and 64 percent, respectively, where stream losses occurred in the Peace River at Zolfo Springs and Payne Creek basins. The largest change of natural stream channels to phosphate mining was in the Payne Creek (54.8 miles) and the Peace River at Zolfo Springs (31.6 miles) basins.

Loss of natural stream channels in now urban land use areas totaled 37.5 miles and made up about 11 percent of the loss. Urban land uses in the place of former natural stream channels was greatest in the Coastal Lower Peace (24.8 miles) basin. Urban land uses replaced 24.8 miles of natural stream channels in the Lower Coastal Peace basin and 8.9 miles in the Peace at Bartow basin, compared with a total of 3.9 miles in the remaining seven basins. Agriculture accounted for 64.5 miles, or 18.8 percent of the natural stream channels lost between the 1940s and 1999, and this replacement ranged from 4.0 acres in the Joshua Creek basin to 9.8 acres in the Peace River at Bartow basin.

Table 4.4. Change in Natural Stream and River Channels (linear miles) in the Peace River Watershed from the 1940s to 1999

Basin	Miles Lost			1999 Land Use in Place of Lost Stream Segment						
	1940s	1999	Change	Urban	Mining	Agriculture	Lakes	Upland habitat	Wetlands	Other
Peace River at Bartow	95.9	38.1	57.8	8.9	10.3	9.8	2.7	7.1	18.7	0.3
Peace River at Zolfo Springs	290.0	240.6	49.4	0.3	31.6	7.8	2.0	1.7	5.9	0.0
Payne Creek	128.7	61.7	66.9	0.4	54.8	6.2	1.1	1.9	2.4	0.1
Charlie Creek	185.8	175.7	10.0	0.0	0.0	6.8	0.1	1.0	2.0	0.0
Peace at Arcadia	133.6	115.7	17.9	0.1	0.0	7.2	0.3	0.1	6.8	4.4
Joshua Creek	57.9	44.2	13.7	0.7	0.0	4.0	0.1	1.4	7.6	0.0
Horse Creek	170.7	140.1	30.6	1.9	4.0	8.6	0.3	6.3	7.2	2.2
Shell Creek	93.0	74.1	18.9	0.3	0.0	7.2	5.4	3.0	2.5	0.5
Coastal Lower Peace	397.7	320.2	77.5	24.8	0.5*	6.8	0.9	13.4	18.7	12.3
Total	1,553.2	1,210.5	342.7	37.5	101.2	64.5	12.9	36.1	71.8	19.8

* Sand/shell mining

Figure 4.2. Developed Land Use in the Peace River Watershed in the 1940s

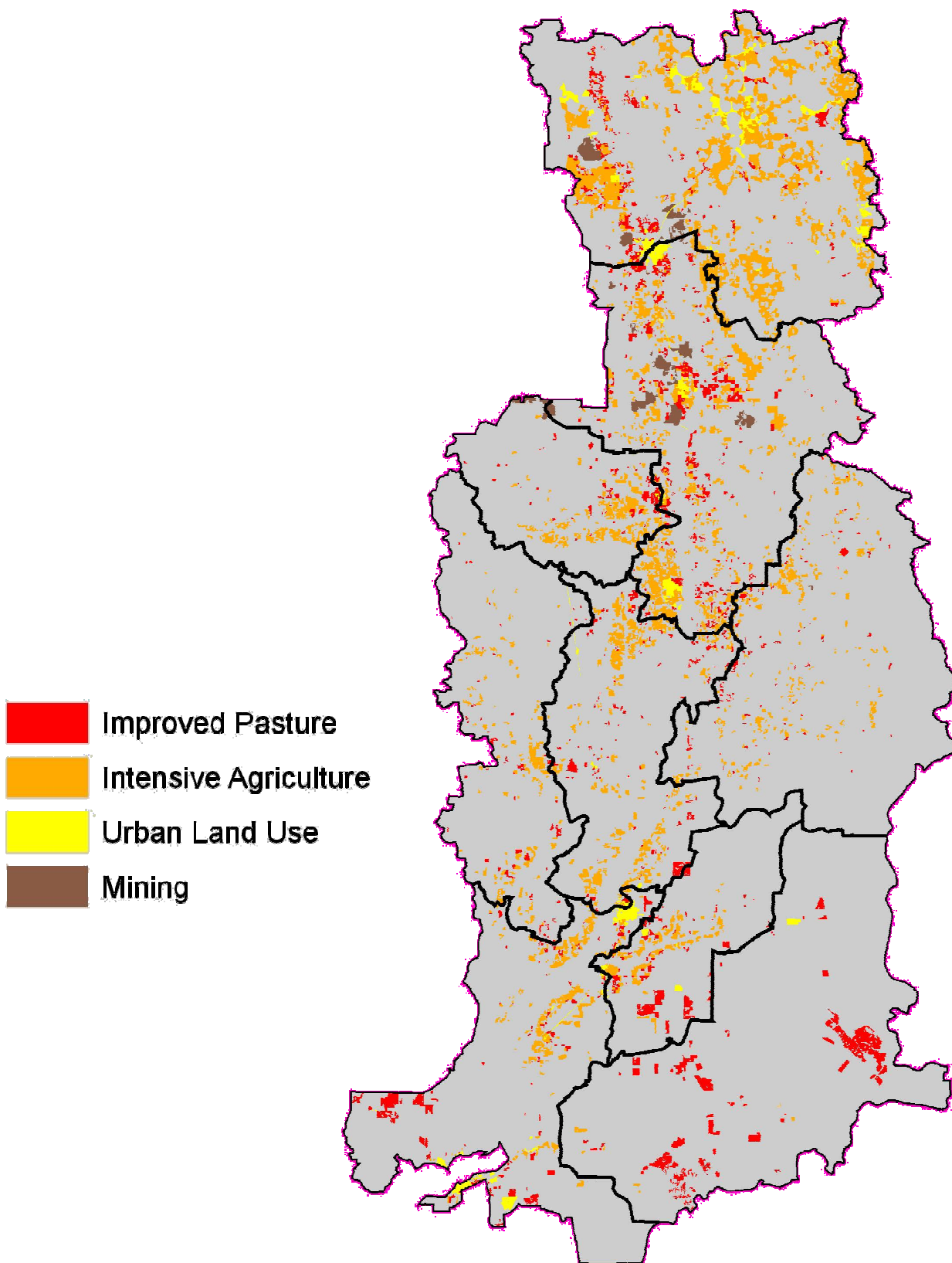


Figure 4.3. Developed Land Use in the Peace River Watershed in 1979

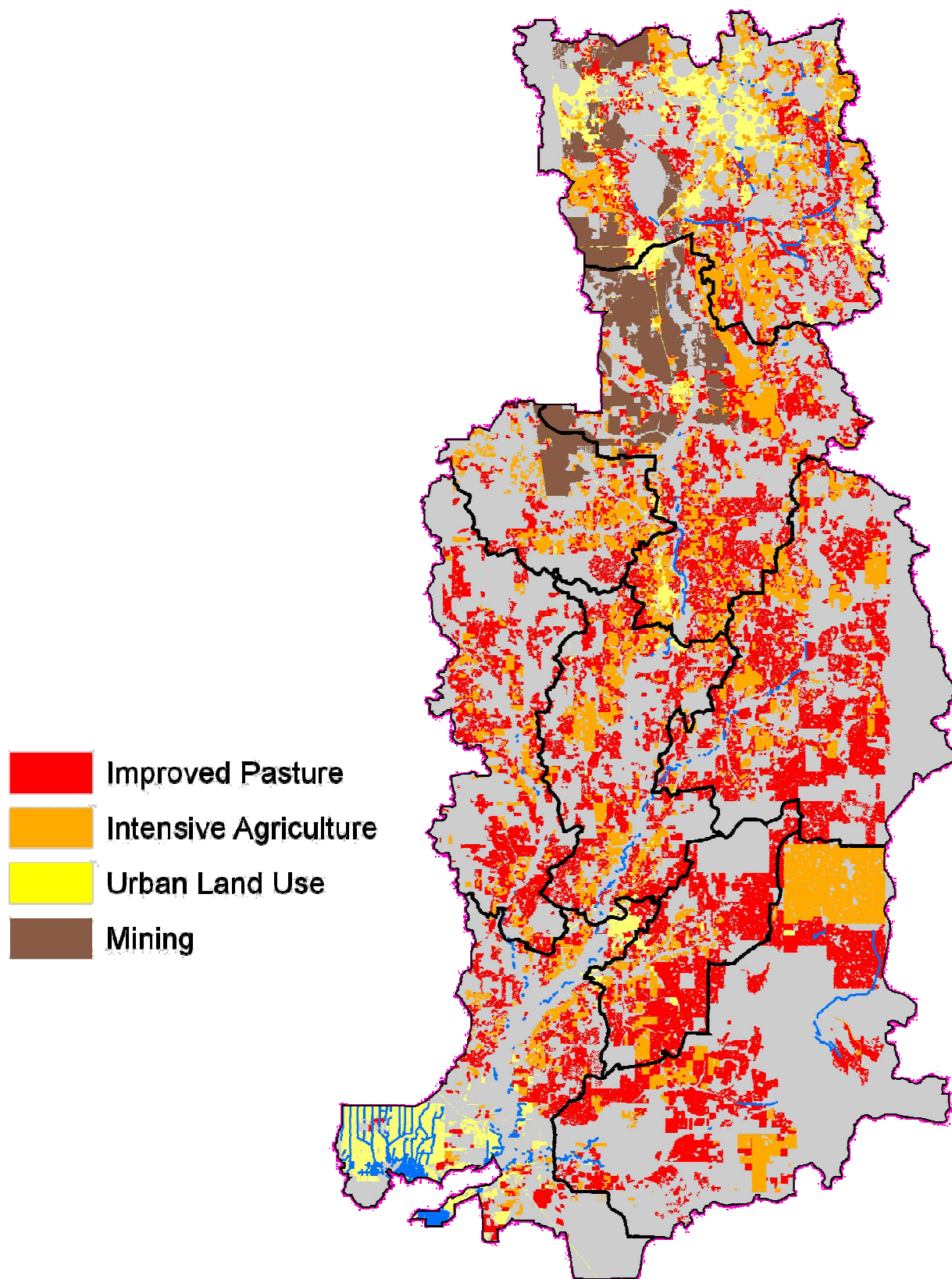


Figure 4.4. Developed Land Use in the Peace River Watershed in 1999

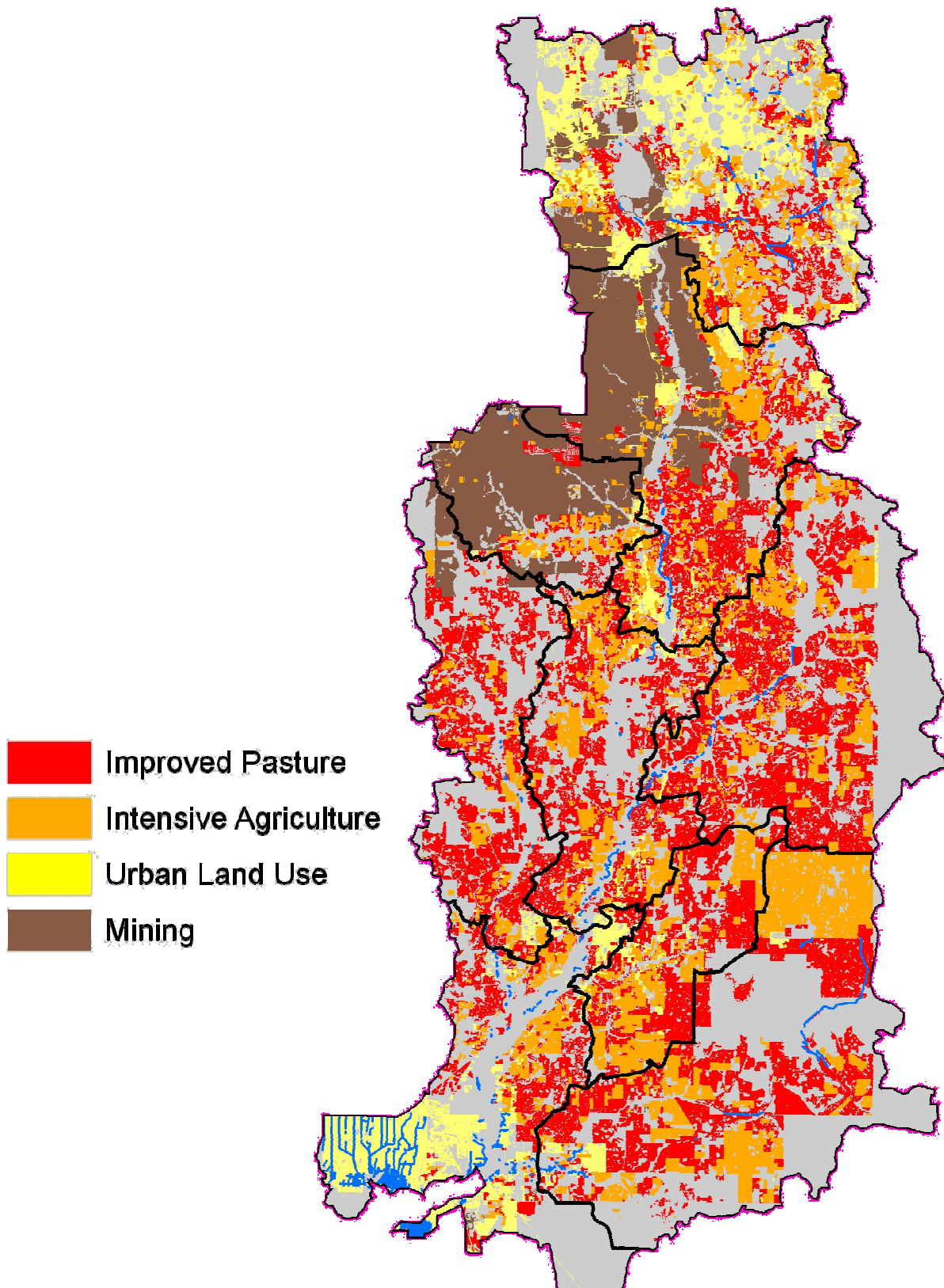


Figure 4.5. Undeveloped Land Use in the Peace River Watershed in the 1940s

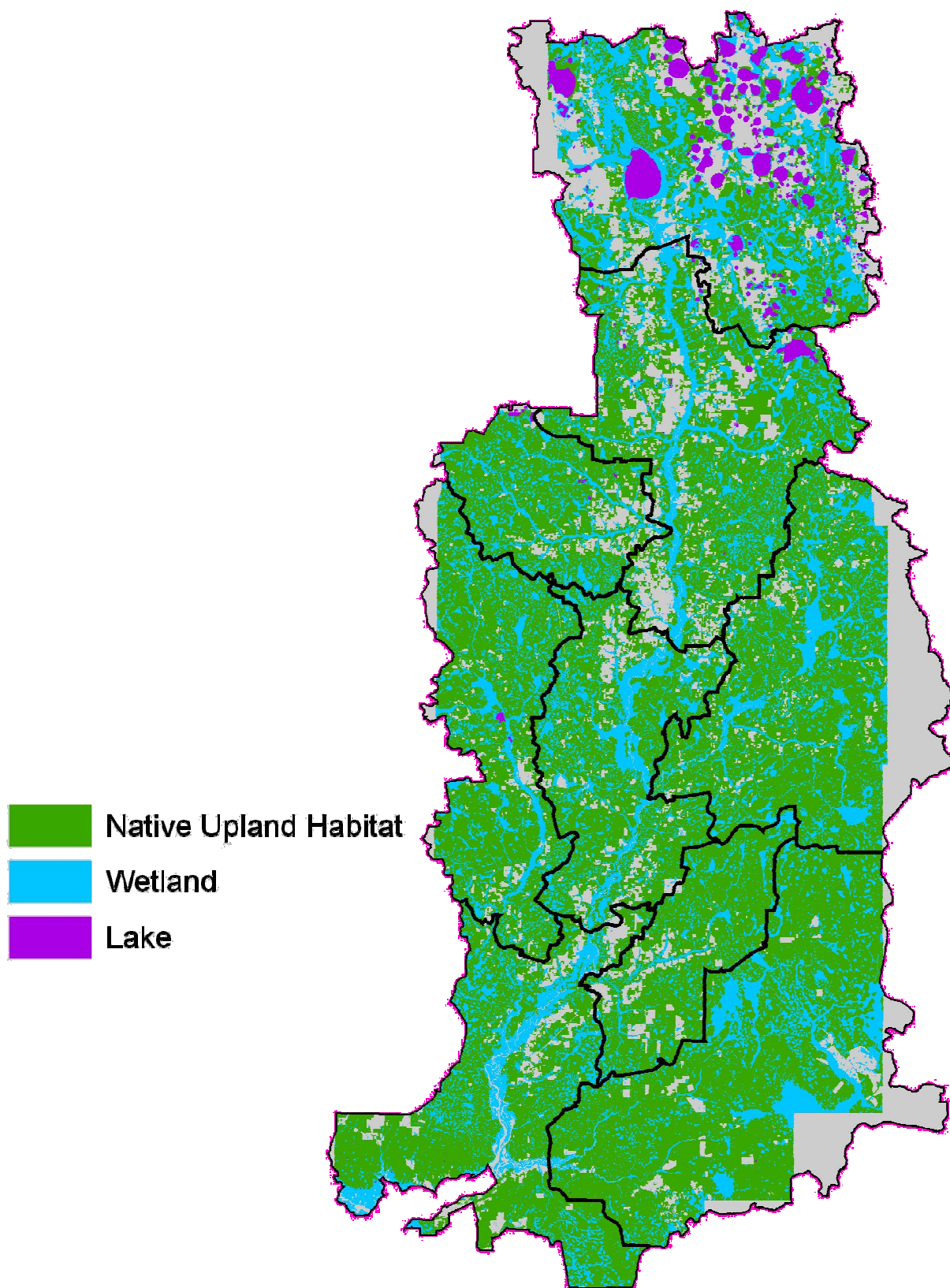


Figure 4.6. Undeveloped Land Use in the Peace River Watershed in 1979

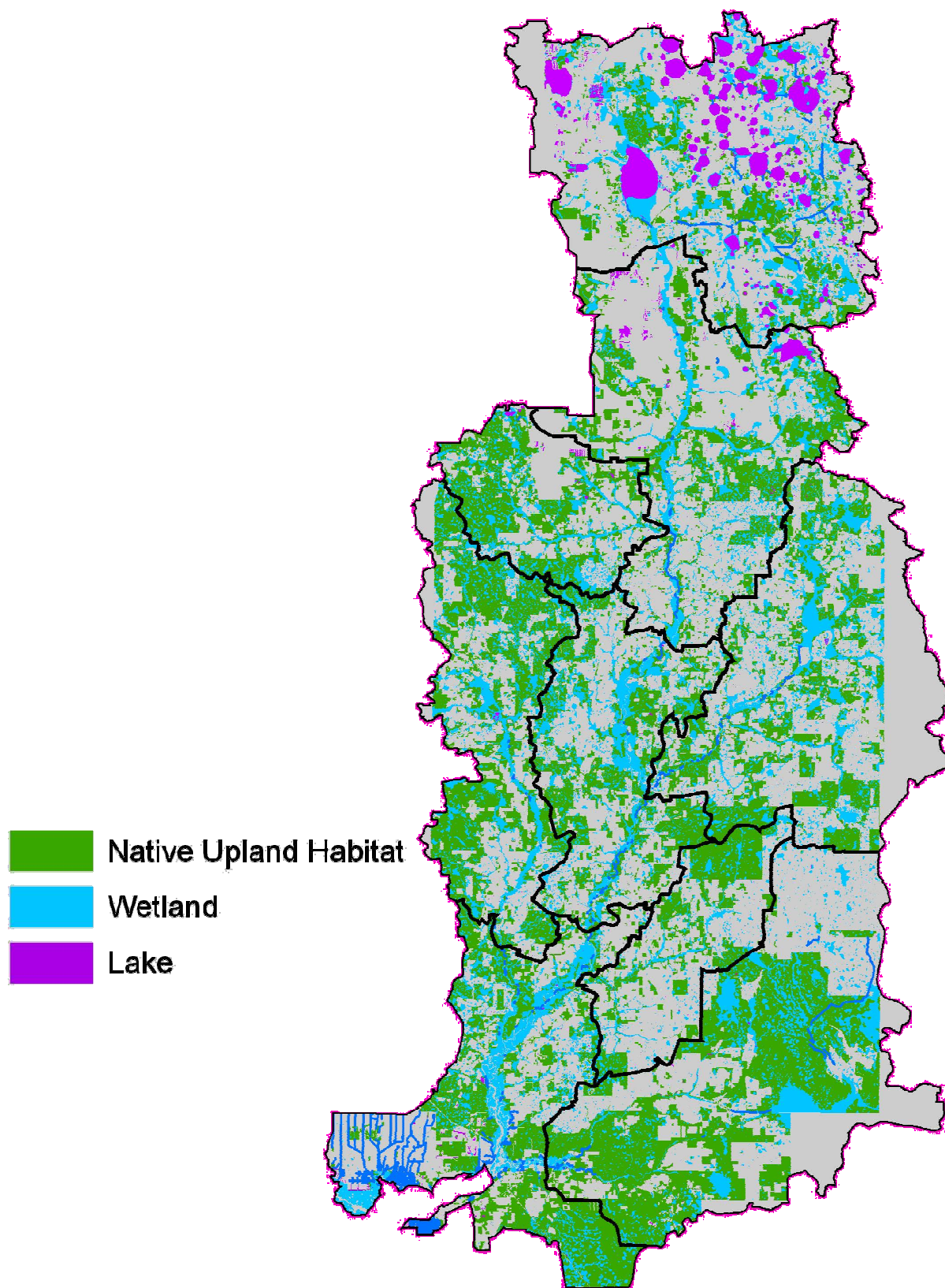


Figure 4.7. Undeveloped Land Use in the Peace River Watershed in 1999

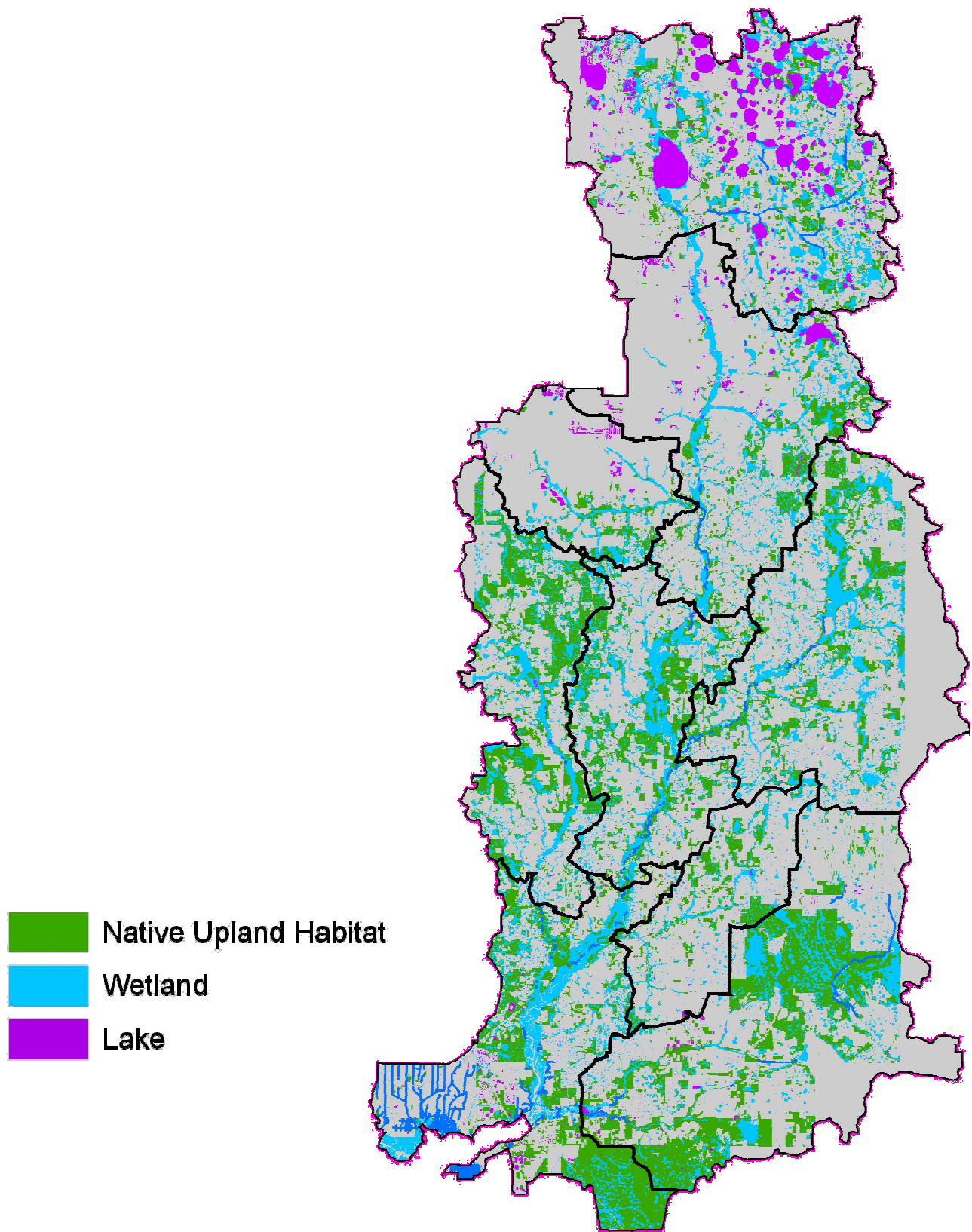


Figure 4.7. Natural Stream and River Channels in the Peace River Watershed Circa 1940s



Figure 4.8. Natural Stream and River Channels in the Peace River Watershed in 1999

