

A multi-criteria assessment of the C-111 hydrologic restoration project – A case study

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Received: 19 December 2013 / Accepted: 30 March 2014 /
Published online: 8 May 2014
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Abstract The hydrologic restoration of the Everglades ecosystem is underway within the C-111 basin. Some early projects have been operating for over 10 years and can now be quantitatively assessed. Some recent research presented in Wetlands provides a good beginning. This research article complements those efforts with a broader project assessment by focusing on buffer lands east of Everglades National Park and in the adjacent water control canal system. This article reviews the restoration progress of the C-111 Project over 12 years against its original performance metrics established in 1999–2000 using a multi-criteria assessment methodology. The authors, including members of the original project design team, discuss the original design hypotheses and then organize the assessment into quantity, quality, timing, and distribution (e.g. QQTD) metrics consistent with the overall restoration objectives of the Everglades system. The assessment is unique given that the original designers were afforded a rare opportunity to see how well their restoration plan actually worked. The broad assessment that was completed includes a 28 year water budget of the L-31 N/C-111 Canal located on the boundary of the Everglades; an accounting of undesirable discharges to Barnes Sound/Manatee Bay; an assessment of hydrologic restoration of buffer land wetlands; an assessment of water quality in the study area; and, an assessment of flood impacts. The study results reveal a mixed record of success for the original restoration plan.

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Keywords Restoration planning · Everglades · Hydrology · Water control · Adaptive management

1 Introduction

Hydrologic and environmental restoration of watersheds, streams, wetlands, and estuaries is underway around the world. However, the planning, prioritization, and assessment of these efforts have been uneven at best (Shisler et al. 2008). In urbanized environments, habitat restoration is even more challenging due to competing land use and divergent needs (Simenstad et al. 2005). A particular challenge is to assess the success of a particular project (Grayson et al. 1999). Recently, a rare opportunity was available to assess the C-111 project adjacent to Everglades National Park (ENP), USA. The multi-purpose restoration project has been operating for over 12 years and is now being assessed by a cadre of scientists and engineers. The scientists are focused upon ENP itself while the engineers are evaluating a broader array of restoration objectives. Lessons learned from this assessment are applicable to many larger future Everglades restoration projects.

The eastern edge of ENP is located near Homestead, Florida which is located southwest of the city of Miami, Florida USA (Fig. 1). The area is characterized by low lying topography comprised of a mosaic of natural wetlands, novel wetlands, agricultural lands, and urban development. ENP, a World Heritage Site (National Park Service 2013) is a massive sub-tropical, freshwater wetland system located in an urban environment. Urban wetlands like ENP are subjected to a variety of anthropogenic stressors (Solecki et al. 1999). For ENP, the most critical stressor is the hydrology, which is influenced by drainage canals in the area (Armentano et al. 2006). The canal system was designed and constructed by the U.S. Army Corps of Engineers (USACE) in partnership with the South Florida Water Management District (SFWMD) with the primary canal, L-31 N/C-111 running generally north to south in the study area. Intensive water management within the basin has been underway since the 1970s; at the same time, the basin was becoming increasingly urbanized and wetlands east of ENP were being converted to agricultural lands or commercial/residential development (Renken et al. 2005; Godfrey and Catton 2012). Recognizing the changing nature of the basin and effects of water management on wetlands in the basin, the SFWMD developed a water resources improvement plan in 1983 (SFWMD 1983).

The planning study proposed a multi-purpose set of improvements including:

- Land purchase of major portions of the basin for floodwater retention and environmental preservation;
- Partial backfilling and elimination of certain canals;
- New pumping facilities;
- Dispersion of freshwater across marshlands; and,
- Redistribution of flow away from Manatee Bay/Barnes Sound into Florida Bay.

The primary restoration objective of the project was to mitigate near-field flooding of agricultural lands while simultaneously rehydrating important wetlands adjacent to and within ENP.

Over the next 20 years, USACE and SFWMD worked on this concept in fits and starts (U.S. Army Corps of Engineers 1994; U.S. Army Corps of Engineers 2002). From 2000 to 2004 a series of large artificial recharge/infiltration basins were installed in the buffer lands east

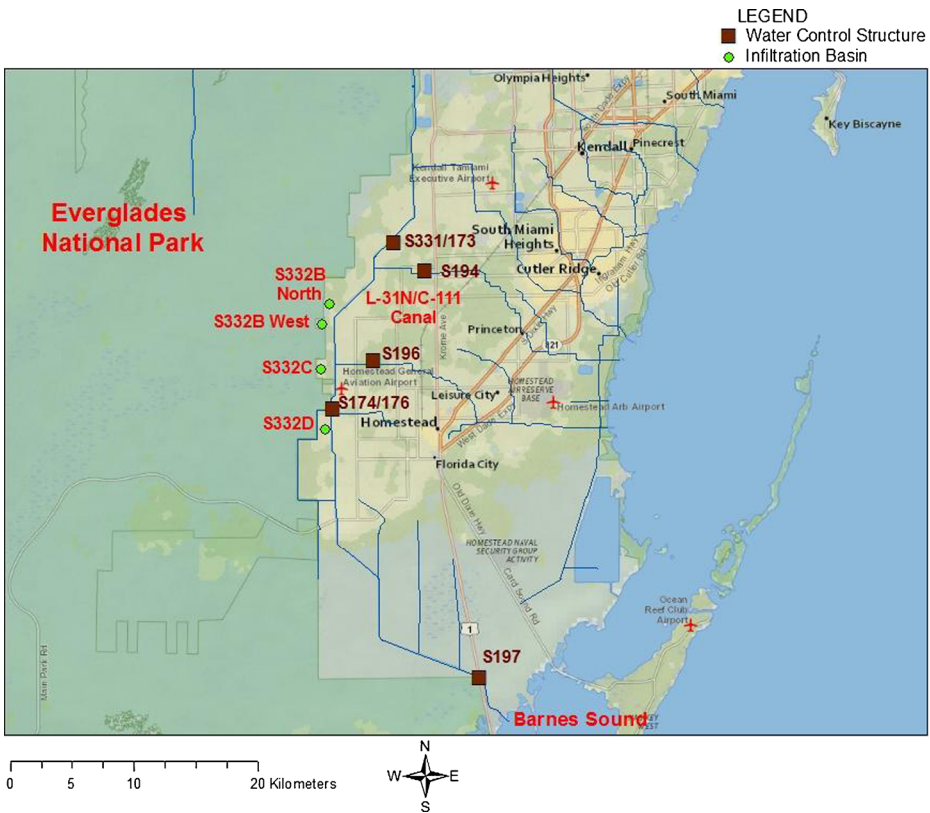


Fig. 1 Overview of project study area in southern Florida, USA showing location of pertinent water control structures, infiltration basins, ENP, and Barnes Sound

of ENP purchased by SFWMD; additional modifications were made in 2007. The 4 primary basins, S-332B West, S-332B North, S-332C, and S-332D, began operating in 2001 with full implementation by 2004. The basins have been operating since that time. Figure 2 depicts a detailed study area map showing location of pertinent water control structures, infiltration basins, and 5 key observation wells discussed in later sections of this paper. Recently, a special issue of Wetlands was developed to assess current wetland conditions within the Taylor Slough drainage located just west of the L-31 N/C-111 Canal. Sullivan et al. (2013) assessed hydrologic restoration of wetlands in the Taylor Slough area. Gaiser et al. (2013) evaluated water quality effects on diatoms and microbes within ENP. Kotun and Renshaw (2013) summarized overall water management and operational changes to the ENP hydrology. This study, completed by members of the original design team, provides a necessary complement to these fine efforts. This paper evaluates the broader, overall performance of the L-31 N/C-111 Project itself using a multi-criteria assessment methodology. Members of the original design team were afforded the rare opportunity to assess 12 years of project operating data. This original research focuses on the canal system itself and the restored buffer lands east of ENP that were acquired for the C-111 Project. The multi-criteria assessment is framed against the original design hypotheses devised by USACE and four primary performance categories including water quantity (Q), quality (Q), timing (T), and distribution (D). Different

quantitative metrics are used to assess the project performance in each category. In describing this research effort, this paper is organized into 4 sections including:

- C-111 Project planning and design discussion/overview;
- Discussion of multi-criteria assessment methods used;
- Assessment results; and,
- Discussion and conclusions.

2 C-111 project planning and design

The C-111 Project was envisioned as a multipurpose water resources and ecological restoration project from its inception in the early 1980s (SFWMD 1983). The project was always intended to improve flood mitigation efforts while also improving hydrology of wetlands within ENP and in acquired buffer lands. A primary design concept was the creation of a hydrologic buffer or ridge between ENP and the L-31 N/C-111 Canal system. It was thought that the hydrologic ridge would reduce seepage from ENP and change groundwater flow paths in the eastern

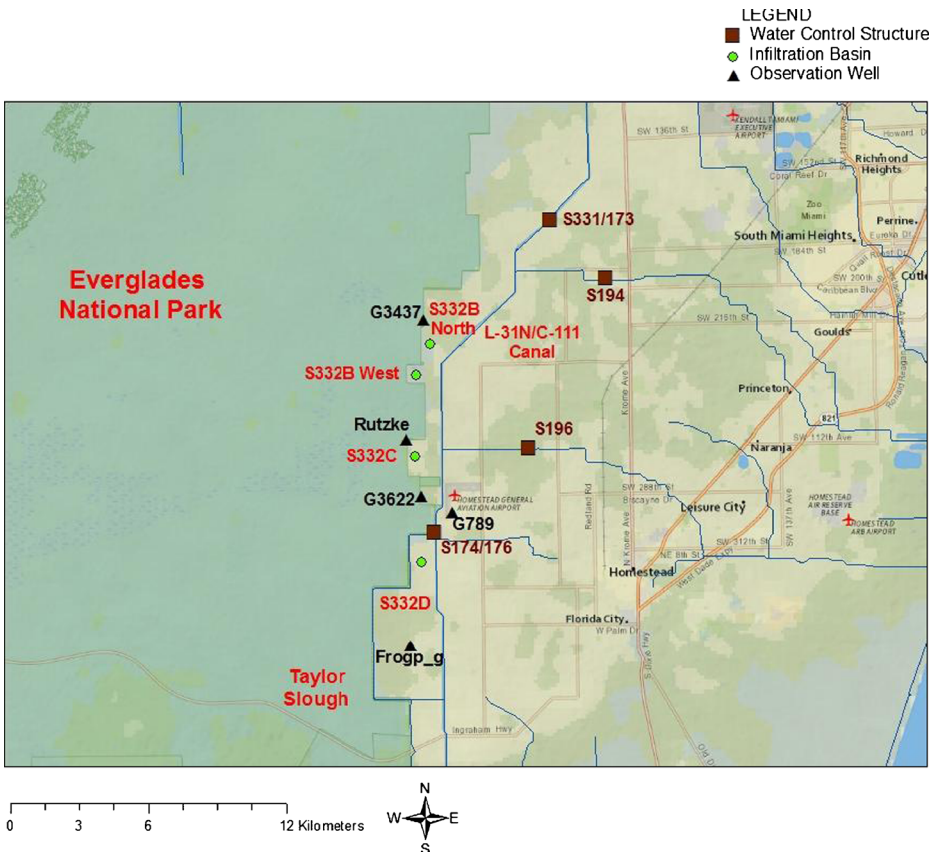


Fig. 2 Detailed project study area in southern Florida, USA

portion of ENP. These design assumptions were supported by preliminary numerical modeling which showed that the hydrologic ridge did provide some benefits even though up to 70 % of the infiltrated water could flow easterly back to the canal system as groundwater return seepage. The final plan, outlined in the General Re-Evaluation Report (GRR) Supplement (U.S. Army Corps of Engineers 2002), included development of buffer area between ENP and urban area extending from the S-331 pump station in the north to the S332D in the south. The various project components were constructed in phases, and at the time of this research effort, are not entirely complete. The first components included filling of several small canals south of S-176 structure and construction of the S-332D pump station just west of the S174 structure. These efforts were completed in about 1999. The S332B West infiltration basin and associated pump station were constructed in the 2000 to 2001 time period. This was followed by construction of further infiltration basins and pump stations (S332B North, S332C, and S332D) in the 2002 to 2007 time period. Prior to basin development, the areas contained citrus groves, specialty fruit trees (e.g. avocados and star fruit), and row crops. The original basin sizes included:

- S-332BN – approximately 93 ha;
- S-332BW – approximately 61 ha;
- S-332C – approximately 122 ha; and,
- S-332D – approximately 324 ha.

The final design of the basins was also based upon a number of other hypotheses developed in 2000. First, the basins were expected to rapidly infiltrate stormwater into the limestone Biscayne Aquifer. The Biscayne Aquifer in the project area is an epi-karst limestone formation characterized by extremely high hydraulic conductivity (Genereau and Guardarino, et al. 1998; Lal 2006; Motz and Brown 2007) with values ranging from about 10,000 to 30,000 m/day. Surface water and groundwater mix readily within this aquifer due to the extensive canal system that exists and due to karst conduits present throughout the formation.

Second, water quality of the stormwater was also reviewed during the design effort. Limited data on the stormwater quality in the canal system existed at the time but the data available suggested total flow-weighted mean phosphorus concentrations were less than 11 ug/l which was similar to the overall nutrient goal for ENP at that time. The design team hypothesized that this quality of stormwater would be compatible with nearby wetlands and other fauna in the study area within the acquired buffer lands and within eastern ENP; an implicit trade-off was made between water quantity and quality (Sanon et al. 2012).

Lastly, due to the extensive historic agricultural operations that occurred in each infiltration area footprint, it was assumed that the surface soils would contain a large mass of nutrients, pesticides, and herbicides. The team reasoned that if the surface soils were left in place, much of the nutrients and contaminants would be leached out of the soils and transported into aquifer and into ENP. In addition, the team hypothesized that leaving soils in place would invite introduction of exotic species instead of more desirable wetland plant types. Therefore, the decision was made to scrape the infiltration basins down to bedrock using conventional excavation equipment.

This research study compares the actual system performance from 1999 to 2011 to the planning and design hypotheses, assumptions, and performance metrics. For some metrics, the basis of comparison was carried back to 1982 in order to provide a strong baseline and permit a more expansive statistical analysis to be completed.

3 Multi-criteria assessment methods used

The research team organized the C-111 Project assessment into four broad assessment categories consistent with the Central and Southern Florida Project Comprehensive Review Study, also known as the “Restudy” (USACE and SFWMD 1999). The four categories are:

- Quantity;
- Quality;
- Timing; and,
- Distribution.

Each of these categories includes different quantitative and qualitative metrics used to assess project performance. In 2000, the Comprehensive Everglades Restoration Plan (CERP) was approved by the United States Congress based on the 1999 Restudy (Godfrey and Catton 2012). Non-CERP projects such as the C-111 and Modified Water Deliveries to ENP are considered foundation projects for CERP and critical to its successful implementation (National Research Council 2010).

The U.S. Congress endorsed the use of an adaptive management approach for CERP. Adaptive management has been considered a fundamental premise of CERP planning and implementation due to the many uncertainties inherent in Everglades restoration efforts (National Research Council 2010, 2012). To support this effort, the U.S. Congress authorized a CERP Adaptive Assessment and Monitoring Program to monitor restoration status, assess progress, and inform the need for adjustments to implementation. In CERP, adaptive management is defined as a structured management approach for addressing uncertainties by testing hypotheses, linking science to decision making, and adjusting implementation, as necessary, to improve the probability of restoration success. This study also helps address some of the adaptive management assessment goals (RECOVER 2011).

4 Quantity

To assess the quantity metric, a system water budget study was completed of the canal system from December 1982 to the end of 2010. The budget was then compared pre-project (e.g. before August 1999) to post-project (e.g. after August 1999). The canal water budget approach is similar to that used by Sullivan et al. (2013) for Taylor Slough watershed inside ENP. The water budget equation was derived using the conservation of mass as follows:

$$+/-\Delta S = P + RO + SW_{in} - ET - SW_{out} + +/-GW_{seep} + +/-Error \quad (1)$$

Where ΔS is the change in storage; P is precipitation directly into the canal system; RO is runoff into the canal system from areas east of the canal system; SW_{in} is surface water flow in through S-331 and S-173 water control structures; ET is evapotranspiration directly out of the canal system; SW_{out} is surface water flow out of the system through S-176, S-174, S-194, S-196, S-332B, S-332C, and S-332D water control structures; GW_{seep} is the seepage in or out of the canal system; and Error is the cumulative errors of all terms. For this study, eq 1 was rearranged to solve for the GW_{seep} in or out of the canal system. All other terms were known or could be readily estimated. Figures 1 and 2 show the location of all surface water inflow or outflow structures along with the four infiltration basins each of whom has an associated pump station. The canal section evaluated for this water budget from S-331 in the north to S-176 in

the south was approximately 16,500 m long with a weighted-mean channel width of 14.61 m and a weighted-mean channel bottom elevation of -2.77 m NGVD 1929. The water budget was calculated on a daily time step and then integrated on an annual basis.

The change in storage, ΔS , was calculated using the daily change in water level in the canal multiplied by canal mean width. The precipitation was the average rainfall recorded at the Royal Palm Range Station rain gage and the Miami International Airport gage. The mean daily precipitation from these two gages was multiplied by the average canal top width to estimate the P input into the canal system. Runoff, RO, from lands to the east of the canal system slopes toward the canal and can provide water inputs into the system. The RO was calculated using the Soil Conservation Service (SCS) Curve Number methodology using a mean curve number of 80 and assuming a contributing watershed of about 26 km^2 . At this curve number value, RO was only generated when daily precipitation exceeded about 1.27 cm. SW_{in} and SW_{out} were estimated using observed daily flow data at the relevant structures. While 100 % of the period of record was available for most structures, the flow into infiltration basin S-332C was incomplete from 2002 to 2005. During this time, flow into the basin was obvious by reviewing nearby observation well water level data so flow estimates were developed using a rating curve approach correlating inflow to groundwater stage at the Rutzke observation well. Daily ET from the canal system was estimated using the annual evaporation potential in south Florida of about 145 cm/year (German 2000). The daily ET rate was multiplied by the average canal top width to estimate the ET flux out of the canal. Due to the small relative contribution of ΔS , P, RO, and ET to the water budget, the most important elements of the water budget are the surface water flows.

Rearranging eq and solving for GW_{seep} in or out leads to eq 2:

$$+/-GW_{seep} = P + RO + SW_{in} - ET - SW_{out} + +/-\Delta S + +/-Error \quad (2)$$

For this study, seepage into the system is negative and seepage out of the system is positive. For example, if the inputs into the system are less than the outputs, the resulting net GW_{seep} term is negative meaning that seepage into the canal system had to make up the water budget shortfall. This is critical as a majority of canal seepage emanates from within ENP. The cumulative error was calculated using an approach presented by Harmel et al. (2006) who looked at cumulative uncertainty in measured streamflow data. Harmel et al. estimated that surface water flow errors would be 6 % to 19 %. Sullivan et al. (2013) used a value of 7.5 % for canal structures for their study of Taylor Slough. This value was also adopted for this study.

5 Quality

Considerable work regarding water quality effects to ENP from the canal system have been ongoing (SFWMD 2002; 2007; Gaiser et al. 2010; 2012). This study simply compiles the various data sources, both published and un-published to provide a broad system assessment.

6 Timing

For the timing assessment, this study evaluates the duration of inundation calculated at five observation wells in the buffer lands along the canal system including G3437, Rutzke, G3622, Frogg_g, and G789. The first four observation wells were evaluated to determine positive changes in wetland inundation in the buffer lands while G789 was examined to determine

changes in agricultural root zone inundation used as an indicator of flooding. Water levels were compared to existing ground elevations at each location to determine the inundation period. Land survey elevations were available from observation wells G3437, G3622, and G789 (United States Geological Survey 2000) and digital elevation model data was available at Rutzke and Frogg_g (Desmond 2007). The root zone was assumed to be within about 61 cm from ground surface for observation well G789.

7 Distribution

For the distribution assessment, evaluations were made within the buffer lands and in eastern ENP as well as water distribution through water control structure S-197 into Barnes Sound. The distribution of flow within eastern ENP was examined using comparison of streamlines pre and post-project consistent with other research efforts in the vicinity (Kotun and Renshaw 2013). Changes in groundwater residence time within ENP are also assessed along pre and post project streamlines. Equations 3 and 4 are used to estimate the mean groundwater seepage velocity and the travel time or residence time of groundwater particles.

$$V = Ki/\varepsilon \quad (3)$$

$$Tt = L/V \quad (4)$$

Where V is the mean seepage velocity along a streamline; K is the horizontal hydraulic conductivity of the Biscayne Aquifer estimated to be 10,000 to 30,000 m/day; i is the mean groundwater gradient along the streamline; ε is the Biscayne Aquifer porosity estimated at 40 % for the upper portions of the aquifer; L is the length of the streamline; and, Tt is the travel time or residence time of a groundwater particle traveling along the streamline.

The distribution of undesirable water flow into Barnes Sound from the canal system was assessed by comparing flows pre and post-project through water control structure S-197.

8 Assessment results

8.1 Quantity

The water budget results clearly show that there is net annual seepage into the canal system for all but one of the years studied (e.g. 1998). The annual seepage totals vary from 2,000,000 m³ out of the canal system (e.g. recharge to the Biscayne Aquifer) in 1998 to a high of about 340,000,000 m³ into the canal system in 2010. Figure 3 shows the variation from 1983 to 2011 including the best estimate and lowest and highest values when factoring in annual mean error which averaged about 20 %. The pre-project mean annual net seepage into the canal system was about 118,000,000 m³ while during the post-project period, the mean annual net seepage into the canal system was about 151,000,000 m³ or an increase of about 28 %. The annual pre-project and post-project net seepage datasets were also compared statistically using the software package PAST (Hammer et al. 2001). First, the pre and post-annual net seepage datasets were checked for normality using a Shapiro & Wilk test (Shapiro and Wilk 1965). Both datasets were determined to be normal with Shapiro-Wilk W values of 0.966 (pre) and 0.929 (post). Then, a simple student T -test was completed to evaluate the probability that there was a true increase in net seepage between the pre and post-project periods. Owing to the large

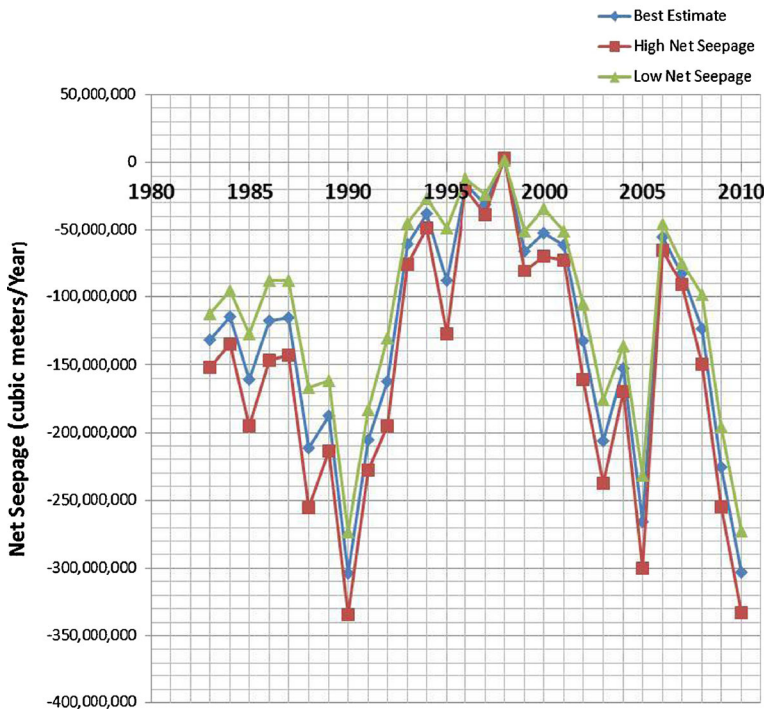


Fig. 3 Annual net seepage to the canal system in cubic meters per year from 1983 to 2010; negative seepage represents seepage into the canal system while positive represents recharge of the Biscayne Aquifer System from the canal system

variance in the data there were no significant differences in the net seepage means at 95 % confidence level, however, the *T*-test did show that there was a 68 % probability that the mean net seepage did in fact increase in the post-project period.

Several checks of the overall net seepage magnitude were also completed. Water budgets were completed in 1999 as part of the Restudy (USACE and SFWMD 1999). Two of the water budgets completed included the Base 1995 (existing condition at the time) budget and the D13R2 (total restoration) budget. These annual water budgets show seepage emanating from ENP and discharging into the lower L-31 N/C-111 system increasing from about 168,000,000 m³/year under Base 1995 conditions to 262,000,000 m³/year under restored conditions. These historic water budgets did not include estimates of recharge from the canal system to areas further east so it was assumed that recharge to the east was about 25 % of the ENP seepage resulting in an estimated net annual seepage of about 161,000,000 m³/year under Base 1995 conditions. That value can be compared with the value 151,000,000 m³/year calculated from this study for the post-project period. Based upon this rough comparison, the overall net seepage magnitudes determined for this study appear reasonable.

During the pre-project period, net seepage flows into the canal system occurred 68 % of the time while the flows out of the canal system (recharging the Biscayne Aquifer) were recorded 32 % of the time. During the post-project period, the seepage temporal distribution did not change much with seepage into the canal recorded 65 % of the time and seepage out of the canal system observed at 35 % of the time.

8.2 Quality

Gaiser et al. (2010, 2013) developed a comprehensive study of water quality in close proximity to the S332 infiltration basins within ENP. The studies included evaluation of soil and water quality as well as assessment of algae, submerged plants, and emergent plants. Overall, these reports provide the following general findings focused upon nutrients:

- From 2000 to 2009 mean water total phosphorus concentrations were about 7 ug/l in the canal system and 6 ug/l in ENP;
- A nutrient enrichment gradient exists from near the infiltration basins (highest values) to away from the basins (lowest values) as measured in mass of total phosphorus contained in periphyton algae; and,
- Biota responded to nutrient enrichment with greater resources near nutrient sources.

Previously unpublished work completed by CH2M Hill under contract to the USACE in 2002 (CH2M Hill 2002) provides further water quality data prior to S-332D basin infiltration start-up and during initial start-up from June 22, 2002 to August 2, 2002. Overall, the report provides the following findings focused upon nutrients and ions:

- Inflow water total phosphorus concentrations ranged from 5 to 13 ug/l;
- Outflow water total phosphorus concentrations ranged from 5 to 23 ug/l;
- Groundwater phosphorus concentrations were observed to be much greater than observed inflow water total phosphorus concentrations; and,
- Inflow potassium concentrations ranged from 2.1 to 3.2 mg/l while potassium concentrations in ENP surface water were generally less than 1.0 mg/l.

The historic data collected at S-332D basin provide the basis for further analysis. First, it was evident that export of total phosphorus occurred from the S-332D “flow way” into Taylor Slough during early project operations. It is surmised that the phosphorus was from disturbed soil sources previously impacted by agricultural operations and higher historical inflow phosphorus concentrations. Second, the groundwater well data lend further credence to the idea that higher concentrations of phosphorus were present in the basin prior to onset of infiltration operations. Lastly, it appears that potassium could be a useful and inexpensive tracer in ENP to better track direct water quality impacts from the C-111 basins.

Looking forward, water quality in the project watershed appears to be improving over time even though the watershed itself is being further urbanized. Phosphorus data was compiled from three annual water quality reports filed by the SFWMD for regulatory purposes. The reports (SFWMD 2002; 2007; 2012) show that flow-weighted mean stormwater phosphorus concentration trends measured in Taylor Slough suggest future phosphorus concentrations will be about 7 ug/l or possibly less compared to values greater than 10 ug/l prior to 2000. Figure 4 (adapted from SFWMD, 2012) shows computed flow-weighted mean total phosphorus concentrations within the C-111 Canal system since 1991 using measurements taken at key water control structures.

8.3 Timing

The assessment results for timing were focused upon the eastern portions of ENP and the acquired buffer lands. Figure 5 shows the results of the pre and post-project assessment in

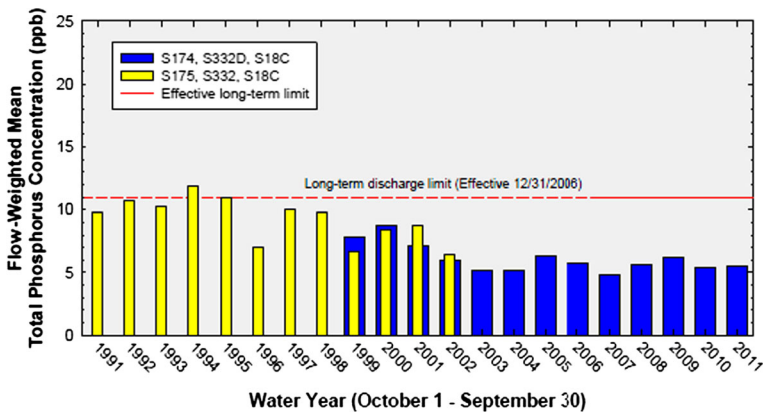


Fig. 4 Annual flow-weighted mean total phosphorus concentrations observed in the lower C-111 canal system

regards to inundation of wetlands as measured at observation wells G3437, Rutzke, G3622, and Frogg_g along with the root zone inundation at G789. Observation wells G3437, Rutzke, and Frogg_g show substantial improvement of wetland inundation post-project. For example, the percentage (%) of time that wetlands at G3437 were inundated above ground surface increased from about 3 % to about 18 %. Similarly, at Rutzke, buffer wetlands were inundated above ground surface from less than 5 % of the time to about 30 %. At observation well G3622 a minor improvement was realized post-project. At Frogg_g inundation increased from about 30 to 55 % of the time. Considering flooding east of the canal system, only observation well G789 was utilized owing to the limited periods of record available for other flood mitigation observation wells (e.g. Humble). At G789, root zone inundation increased slightly during the post-project period. Due to small inundation changes observed at G3622 and G789, it is not possible to conclude that the C-111 project features and operations were solely responsible.

8.4 Distribution

The assessment methodology for “distribution” evaluated the flow patterns in the eastern ENP/buffer lands and distribution of undesirable flows into Barnes Sound. Within eastern ENP, this study looked at flow paths and changes to streamlines as a result of the four infiltration ponds. Figures 6 and 7 provide an example of typical changes resulting from operation of the infiltration ponds during the post-project period. Figure 6 shows study area 1997 water levels relative to NGVD 1929 m. Stream lines are drawn perpendicular to the water level contour lines. Figure 6 depicts five such stream lines emanating from within ENP on September 10, 1997 or pre-project. Figure 7 shows the effect of the S332BW infiltration basin testing and S332D pump station operation during September 10, 2001 during the post-project period. Five stream lines are shown again starting from identical areas as Fig. 7. Due to the operation of S332BW the second streamline (from the east) is forced further north of its 1997 location while the third streamline is forced further south of its 1997 location. The direct effect of the infiltration basins is to keep some groundwater in ENP longer than without the project. A case in point is illustrated by comparing the third streamline from 1997 to 2001. The length of the streamline is increased in 2001 from about 7,620 m (in 1997) to 12,527 m. Also, along the same streamline the gradient towards the canal system from ENP is reduced from about 7×10^{-5} to 1.8×10^{-5} when the project

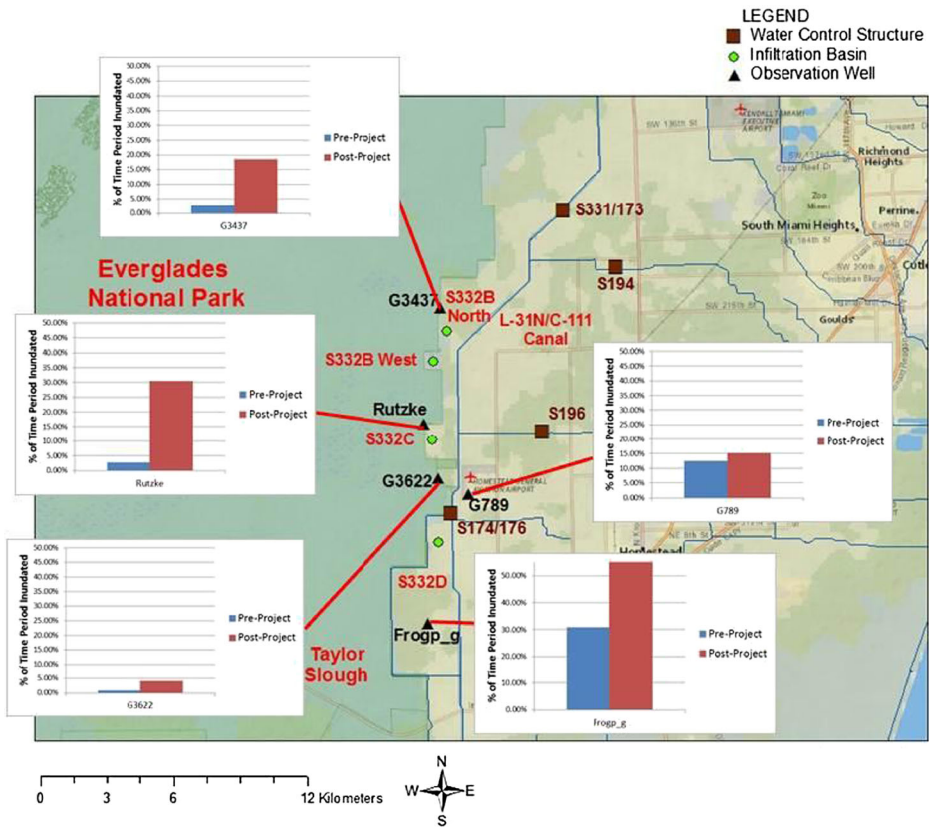


Fig. 5 Analysis of results for timing (T) at five observation wells showing percentage inundation during pre and post-project periods

is in early testing and operation in 2001. The combined effect of these two variables is to increase the residence time of groundwater particles flowing along the streamline in ENP by about 6 times based upon calculations performed using equations 3 and 4. In addition, the effective zone of influence of the infiltration basins is estimated to extend from about 2 to 2.5 km from the western edge of the ponds when all are operating simultaneously.

In a review of flow distribution from the canal system into Barnes Sound and Manatee Bay, surface water flows out water control structure S-197 were reviewed and compiled. During the pre-project period, mean annual flow volumes into Barnes Sound were about 43,000,000 m³ while in the post-project period the mean annual flows were about 25,000,000 m³. The undesirable flow volumes into Barnes Sound were reduced by about 42 % on an average annual basis. Using PAST again, an additional comparison was made of the annual flow volumes out S-197 from 1983 to 1999 (pre-project) and 2000 to 2011 (post-project) using a Mann–Whitney statistical test of medians. The Mann–Whitney test concluded that the median flow during the post-project period was significantly lower than during the pre-project period at *p*=0.10 significance level. In addition, during the pre-project period, flows out the S-197 structure were recorded about 6.7 % of the time versus only 4.2 % of the time during the post-project period.

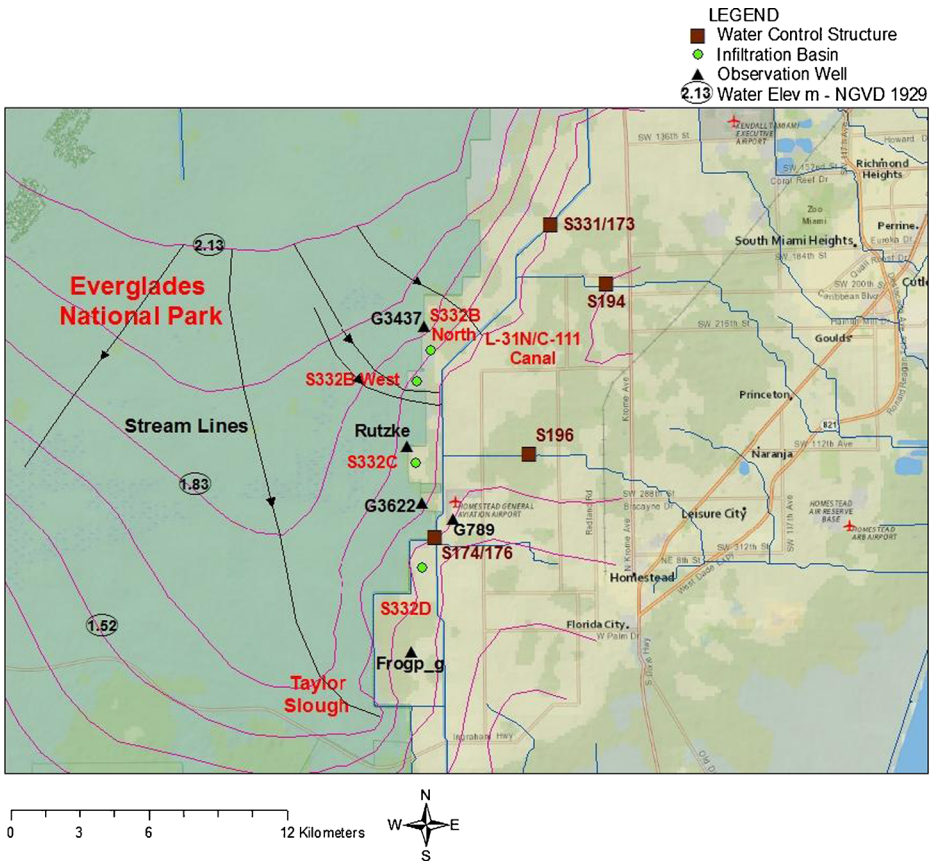


Fig. 6 Analysis results for distribution (D) looking at September 10, 1997 water level contours (in pink) and groundwater flow paths (lines with arrows)

9 Discussion and conclusions

This study and others (Hopfensperger et al. 2006) demonstrate the value of periodically reviewing the performance of previously designed and constructed restoration projects. This study evaluated the broad performance of the C-111 project against standard Everglades Restoration goals for water quantity, water quality, water timing, and water distribution. The study also looked at other design assumptions and hypotheses developed for the project in 2000. Project specific conclusions are provided herein.

The water quantity changes resulting from the C-111 project implementation were assessed using a long-term water budget of the canal system itself. The study determined that net seepage into the canal system has increased from the pre-project period by about 28 % mostly due to infiltration basin seepage return flows. A statistical analysis determined that while this increase was not significant at the 95 % confidence interval, it was probable. Other indirect measures support this conclusion also. Ongoing research of the northern canal basins upstream of this project area suggest that seepage into the canal system decreased based upon operations during the 1999 to 2011 post-project period. This is viewed positively of course, but, it also means that moderately less water deliveries are provided to the lower C-111 basin than were likely

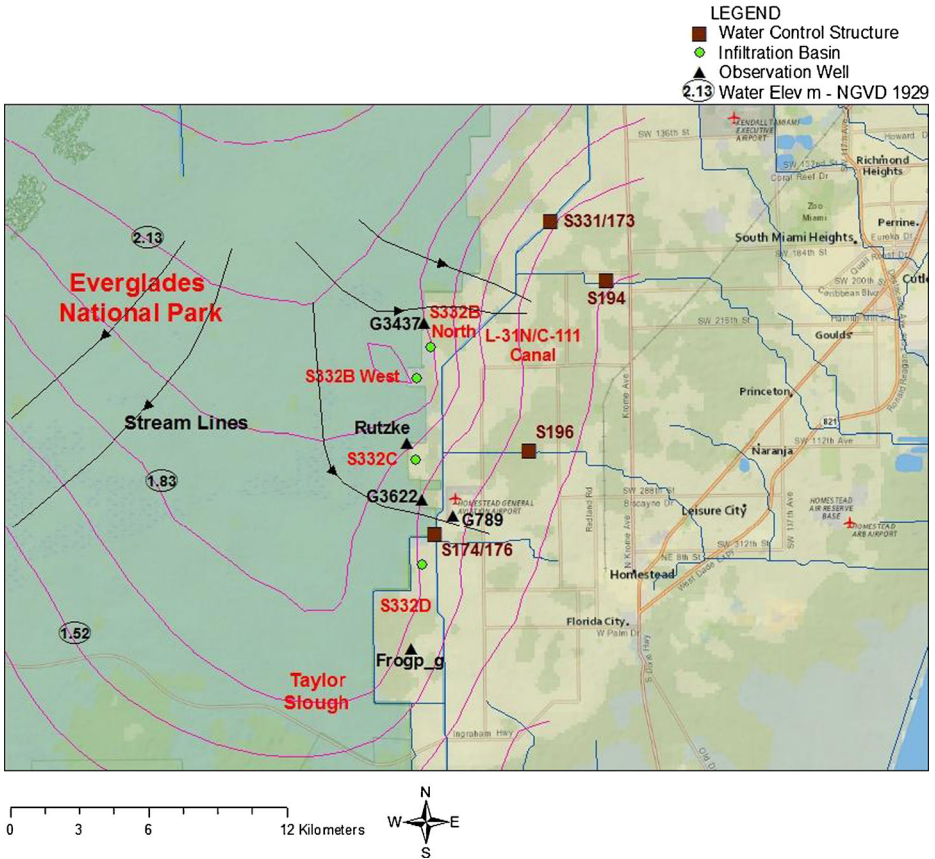


Fig. 7 Analysis results for distribution (D) looking at September 10, 2001 water level contours (in pink) and groundwater flow paths (lines with arrows)

required. Other C-111 data evaluations also support this notion. For example, the ratio of total flows into the 4 infiltration ponds to the inflows through S-331/S-173 structures has increased during this time from about 0.54 in 2000 to 1.85 in 2010. This means that local groundwater seepage is providing the bulk of the basin outflows in the later portions of the post-project period versus basin inflows. The USACE, SFWMD, and other project partners (ENP, locals) may want to consider implementing further operational changes to the system to ensure that there is a better balance between basin inflows and outflows to the infiltration basins to minimize groundwater “mining” in the study area. The data also reveal the importance of analyzing the Everglades as a “system” rather than as isolated projects.

The water quality changes resulting from the C-111 project implementation were assessed by compiling published and unpublished water quality data for the project and evaluating long-term trends. Gaiser et al. (2013) clearly prove that some changes to ENP biota have already occurred due to higher nutrient inflows from the C-111 project. The changes are likely confined to within about 2 km from the western edge of the infiltration basins which represents the primary area of influence for the project. Total flow-weighted mean phosphorus trends within Taylor Slough indicate that concentrations have decreased over the past 20 years (see Fig. 4) and may decrease further due to more stringent water quality regulations and best

management practices within the basins. So, the research team believes that observed water quality effects on ENP flora and fauna are temporary and may be mitigated over time. There may be limitations to what other active management options could provide in regards to water quality; limiting choices of project overseers. This is consistent with practical recommendations made by Zweig and Kitchens (2010) who note that parts of ENP are more novel ecosystems now and may never be fully restored to “natural conditions”. An opposing view is afforded by the National Research Council (2012) that noted that near term progress that addresses only water quality or water quantity will lead to continued system declines in the Everglades. They contended many improvements in water quality are linked with improvements in water quantity, thus decisions on Everglades restoration project design and scheduling should not be viewed as simple tradeoffs between water quality and water quantity. Further technical debate in this regard is warranted.

Part of the planning and design for the project hypothesized that scraping off the agriculturally-changed soils would reduce the invasion of non-native exotic species and permit succession by more native wetland plants. Preliminary studies (Gaiser et al. 2010) suggest that exotics such as Brazilian Pepper (*Schinus terebinthifolius Raddi*) have indeed been kept at bay, however, others such as common reed (*Phragmites australis*) have appeared in the infiltration basins themselves. Other recent studies within ENP suggest that over the long-term, scraping of the nutrient-enriched soils will be beneficial (Smith et al. 2011) by minimizing invasion by exotic plant species. Therefore, based upon observation and supporting research, it appears that basin scraping was a suitable design approach that should be considered for other future projects.

The water timing changes resulting from the C-111 project implementation were assessed by looking at pre and post-project wetland inundation within the buffer lands and just east of the project. Inundation was measured as the percentage of time water levels were above ground or within the root zone. Assessment results clearly indicate improvements in wetland hydration at G3437, Rutzke, and Frogp_g. Results at wells G3622 and G789 were inconclusive. Based upon the location of these instruments, larger effects were expected. At G789, it appears that the C-111 Canal itself is providing a moderating effect on water level changes. The results at G3622 are more perplexing given its proximity between two of the initial basin sites. One hypothesis to explain the results is the presence of larger karst features located to the west of the instrument. In a review of some water level contour maps in the area (e.g. Sept 10, 2004), abnormally low water levels were observed west of G3622 during some periods. A larger karst feature present in this area could shunt recharge water directly back to the C-111 Canal bypassing the instrument entirely. Further geologic study is probably warranted in this area.

The water distribution changes resulting from the C-111 project implementation were assessed by evaluating changes to groundwater streamlines emanating from ENP as well as evaluating changes in flow to Barnes Sound. The C-111 project appears to provide significant hydrologic benefits to ENP when it is operating by increasing groundwater flow residence time of particles emanating from within eastern ENP. A reduction of flows into Barnes Sound was identified as another primary C-111 project goal in the distribution category. This study demonstrated that flows into Barnes Sound through water control structure S-197 were reduced by about 42 % during the post-project period. A Mann–Whitney statistical test comparing median flows determined the reduction to be significant at the 90 % confidence interval. The flow reduction finding at the S-197 water control structure (the end of the canal system) is consistent with the other evaluation data discussed herein. Less water than necessary was delivered through S-331/S-173 causing make-up water for the restoration pump stations to be largely derived from groundwater seepage. Overall, S-197 is used less during the post-

project period because of this. Further studies are required to determine if the flows that were not directed to S-197 were truly redirected to Florida Bay instead which represents the planned ecosystem beneficiary of this strategy.

Acknowledgments The authors gratefully acknowledge editors and authors from the recent Special Issue of Wetlands devoted to the Everglades who started the overall assessment of the C-111 project and whom helped spawn ideas for this paper. The authors also acknowledge the review by 3 anonymous reviewers who helped to improve the manuscript. It should also be noted that the views expressed in this paper are those of the authors themselves and are not those of the USACE or SFWMD.

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