Aquifer Recharge Well Site Suitability Mapping

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ABSTRACT

As the supply of fresh groundwater resources becomes increasingly limited in Florida due to population increase, water resource managers are looking for alternative water supply projects to support fresh groundwater demand for people, agriculture, and other demands. One alternative water supply approach in Florida is to divert surface water into the karstic aquifer through water wells (aquifer recharge wells); however, there are many criteria to consider when selecting a site for an aquifer recharge (AR) well. Several studies show that scoring the different criteria and completing a final calculation can ultimately help identify the optimal location for the AR well, but the scoring criteria and methods are not consistent among these studies. This paper serves to compare the non-GIS-based (HSW Project) and GIS-based (Hunter Project) scoring methods used for a proposed AR well project in north central Florida (the Upper Suwannee River Regional Aquifer Recharge Project) to the scoring methods found in literature (the Amineh and Smith Projects described below and a review of 63 projects by Sallwey et al.). The evaluation of these scoring methods can ultimately provide guidance and considerations for future selection of aquifer recharge well sites located in areas with karstic aquifers. This guidance provides a consistent, reproducible, GIS-based approach for water managers to consider when selecting the best sites for AR wells.

INTRODUCTION

As groundwater pumping from the Upper Floridan Aquifer (UFA) is projected to increase through 2030, the Suwannee River Water Management District (SRWMD) is tasked with completing alternative water supply projects that contribute to recovering aquifer levels and mitigation of water resource impacts (SRWMD, 2011). The SRWMD currently proposes a project, the Upper Suwannee River Regional Aquifer Recharge Project, to construct four AR wells within the Upper Suwannee River Basin within the state of Florida shown in Appendix Figure A (area of 2,343km^2 or 904.9mi^2). This project is a regional strategy to increase the amount of water recharging the UFA and ultimately raising groundwater levels (the potentiometric surface) in the UFA (HSW, 2018). The project focuses on diverting above normal surface water flows, when available, from tributaries along the Upper Suwannee River into recharge wells connected to the UFA (HSW, 2018). To select the first of four possible sites for the construction of an AR well, the District selected an engineering firm to complete a site selection pre-design study (HSW Project) and the engineer opted to use a scoring matrix to compare the sites.

In 2018, HSW Engineering, Inc. (HSW) completed a pre-design study (HSW Project) with the goal of identifying the optimal site within the Upper Suwannee River Basin to begin construction of the first well. HSW used a scoring method (non-GIS based approach) to determine which watershed was the most suitable for the first AR well. The Hunter Creek Watershed (Appendix Figure A) was identified by HSW as the most suitable location for the first recharge well. Prior to the completion of the HSW Project, a separate GIS-based site selection project was completed in 2017 by SRWMD staff (Hunter Project) to select the best AR well site within the Hunter Creek basin. The GIS-based site suitability project, focused on the Hunter Creek Watershed (area of 52km^2 or 20 mi^2) within the Upper Suwannee River Basin, was completed and determined areas within the Hunter Creek Watershed that would be most suitable for the construction and performance of an AR well. When comparing the methods used in these projects to those documented in literature (Smith et al., Amineh et al, and Sallwey et al..), it is apparent there is a wide variety of scoring methods, but there was some consistency in the criteria used to evaluate the sites. In comparison, one can also see the benefits and disadvantages for each project.

HSW PROJECT

HSW completed a scoring exercise to determine which site, of eight sites (Appendix Figure B), would be the most suitable site for an AR well. The HSW Project quantitatively and qualitatively scored (from 1 to 3) several categories (Appendix Figure C): ownership/control, construction/permitting, available water for capture, water quality, and other (HSW, 2018). The ownership/control category was based on ownership and proximity to existing wells. The construction/permitting category was based on existing road conditions and actual site conditions including topography, wetlands, and floodplains. The available water for capture reflected the amount of water that could be captured from each basin, if there were existing monitoring stations on the adjacent water body, and the proximity to the Upper Suwannee River. The water quality category reflected water quality results where any water quality thresholds were exceeded (including Al, Fe, Color, pH, and coliform) and availability of water quality data. The other category included considerations for private land, evidence of human activity at the site, and if any other issues were expected at a site. These scores (from 1 being the most desirable and 3 least desirable) were input into a site decision matrix (Appendix Figure D) to determine an optimal site indicated by the lowest score.

The Hunter Creek watershed was selected out of the eight sites considered. This watershed was largely chosen because of the high score for property ownership (i.e. owned by government agencies), because properties already owned by government agencies do not need to be purchased which reduces project cost. Comparing this project to other GIS-based methods, shows some important aquifer characteristics (transmissivity, depth to aquifer, potentiometric surface, etc.) were not considerations for recharge potential which is an important consideration when identifying which site among the sub-basins would be best for aquifer recharge.

Sites with lower transmissivity values, lower head difference, and less recharge potential are least desirable as the goal of the USRARP is to construct an AR well that brings the most surface water into the aquifer. Karstic limestone aquifers are more likely to have transmissivities in a range that allows the movement of surface water into the limestone aquifer. Within the aquifer, the limestone formations have different transmissivity (which is a function of hydraulic conductivity and aquifer thickness) based on the different composition material of the limestone. Limestone is heterogeneous and composed of calcium carbonate-based materials such as fossiliferous limestone, coquina, or dolomite and the calcium carbonate-based materials have different hydraulic conductivity depending on how water moves through the material. Since the goal of aquifer recharge is to move more surface water into the aquifer, it is ideal to identify the sites where transmissivity data is available and choose sites where transmissivity is highest. Transmissivity was considered in the Hunter Project.

HUNTER POJECT

For the Hunter Project, SRWMD staff scored criteria using rules and regulations of the State of Florida, recommendations of state agencies, and physical criteria. There are several criteria to consider when selecting the location for a recharge well, including impacts to wetlands, public accessibility (i.e. vandalism that could drive up maintenance cost), contamination to existing domestic withdrawals from the Florida aquifer, construction accessibility (adequate roads for heavy machinery access), and aquifer characteristics (optimal recharge potential).

It is best to avoid construction of the well within wetlands to reduce the risk of environmental impacts (which can increase project costs associated with wetland mitigation). The Florida Department of Environmental Protection (DEP) follows chapter 62-330, Florida Administrative Code, which requires the avoidance and minimization of impacts to wetlands; therefore, this assessment scores areas outside of wetlands (uplands) higher than areas near wetlands.

To evaluate limited public access to wells**,** parcel data was used to identify and score parcel use type in these categories: public/conservation lands, agriculture, timberland, mining, or other (single family, multiple family, vacant residential, etc.). Priority site suitability or higher scores were given to conservation lands with a score of "20". Timberland was assigned "15", agriculture - "10", mining - "5", and other(s) assigned "0". These scores were selected based on the likelihood accessibility by the public. Sites with limited public access (higher score) are less likely to be vandalized or deliberately contaminated.

Well location information from SRWMD permitted wells was used to determine the location of domestic wells to limit possible impacts to nearby existing legal uses of domestic water wells (i.e. wells used to supply single family homes with water) from the surface water introduced via the AR well. Since the AR well owner is required to maintain control around the proposed recharge well by 1,000 feet (304.8 meters) pursuant to the Class V Injection Well Construction Permit enforced through DEP, a buffer of 304.8 meters was created around each domestic well. Since impacts to these wells could be mitigated by constructing the AR well to a depth exceeding the depths of nearby domestic wells, a value of "-5" assigned to the buffer area. This approach reduces the site suitability score minimally while allowing the preference to avoid these buffer areas if possible. To limit public access to the AR well, street data (i.e. lower use roads compared to highways discussed below) was used to determine locations that are least likely to have public access and/or reduced public travel. The limitation to public access addresses the increased risk of tampering and possible contamination from roadway spills and debris. Streets were identified and a buffer of 304.8 meters was applied (since the proposed well site will need to be accessible by road) and scored “20”. Areas outside of the street buffer areas were assigned “0”.

Certain aquifer characteristics are more favorable to the function of a recharge well. Generally, the greater the head difference between the surface water source and the pressure head (the potentiometric surface) of the Florida aquifer, the greater the recharge potential. If a Floridan aquifer well has a static water level that is at ground surface (i.e., the potentiometric surface is the same as the land surface elevation; head difference is zero) it will not drain. A well that drains (i.e., has a larger difference between the potentiometric surface and land surface) is more likely to recharge water. Transmissivity is also an important aquifer characteristic that signifies the ability for the geologic formation (in this case, different types of limestone) to allow water to flow. A higher transmissivity indicates the ability to move water through the aquifer and is ideal for the location of a recharge well where the goal is to move more surface water into the aquifer. Areas of the UFA known to have higher transmissivities were given higher scores and vice versa.

A last consideration is the need to have the recharge location near Hunter Creek and accessible from a highway. Since construction of the AR site requires the use of heavy machinery, the site needs to be accessible from a main thoroughfare to keep project costs lower. The cost to a road capable of heavy machinery traffic would make the project infeasible. Even though the Streets ranking discussed previously discourages a site directly connected to a highway (to discourage public access), the need for heavy machinery access is an important factor. By ranking both the streets and highways, the selection of existing roads keeps project costs low while giving more ranking weight to highways, but also adding the consideration of streets to the selection process. The location is the most important financial consideration since construction of infrastructure to make the site accessible could consume most of the project budget, so values within 304.8 meters of a highway and within 304.8 meters of Hunter Creek were identified and given the highest score of "50". After creating the score raster files for each of the parameters discussed above, a final raster calculation was completed to add all the scores together. Higher scores (shown in red) are the ideal locations for the construction of the recharge well for the Hunter Creek watershed.

PROJECT OBJECTIVES

To identify and score the most appropriate location(s) for the AR well(s) using the following parameters:

1. Construction of the well is not in wetlands;
2. Parcel use type allows least access to the public;
3. Distance from existing legal domestic use withdrawals from the UFA (>340.8 m);
4. Street access allowing least vandalism (304.8 m);
5. Difference between land surface elevation and the potentiometric surface of the UFA is highest;
6. UFA transmissivity is highest.
7. Construction site as highway access (304.8 m buffer) and well is near Hunter Creek (304.8 m buffer)

Criteria	Score range
Wetlands	0, 10
Parcels	0, 5, 10, 15, 20
Domestic wells	0, -5
Streets	0, 20
Recharge	0, 5, 10, 15, 20
Transmissivity	0, 5, 10, 15, 20
Location	0, 50

Table 1. Hunter Project scoring matrix

PROJECT MATERIALS & METHODS

The following section lists step by step instructions for the methods used to create scored raster files for each attribute that was used to develop the final site suitability map. A flow chart of the methods followed for each attribute can be found in the Appendix (Flow charts 1 – 8).

1. **WETLANDS** – Goal: No construction in wetlands

The website of the United States Fish and Wildlife Service provides the Wetlands Mapper service. After navigating to an area of focus (Hunter Creek for this project), the website gives the option to export the basin wide wetlands map. The basin map exported and used for this project was called "HU8_03110201_Wetlands.shp" (USFWS, 2017). After projecting this data to NAD1983 FLORIDA GDL Albers (meters), the clip tool was used to clip the wetlands information to the Hunter Creek watershed. Following the steps outlined in Flow Chart 1 and described in the Project Steps file, new scores were given based on a land "Class" (uplands or wetlands). Uplands were given a value of "10" and wetlands were given a value of "0". This scoring method gives suitability priority to locations that are outside of wetlands. This score vector file was converted to raster "Wetlands_Score.gdb" to use in the final raster calculation to create the Site Suitability map.

2. **PARCELS –** Goal: Parcel use types with least access to the public

The Hamilton County Florida Property Appraiser's website makes parcel data available for a fee; however, the SRWMD provided the data for this project at no cost. The file Parcels.shp was used for the following parcel scoring process (Hamilton County, April 2018). The file, Parcels.shp was projected to NAD1983 FLORIDA GDL Albers (meters) and clipped to the Hunter Creek watershed file. See Flow Chart 2 for detailed steps. The parcels file includes a field that describes the parcel use, PARUSEDESC. This field was used to identify the different use types determined for parcels. When selecting a location for the AR well, the goal is to have a location that is least likely to be accessed by the public (to reduce chances of vandalism) and provide continuing wellhead protection. Properties described as “Reserved for Future Use” were given the highest score of “20”. These properties were also cross-referenced with conservation lands data that was available from SRWMD. Timberland-related parcels were given a score of “15” because, although they are not protected in perpetuity, little activity occurs at these sites. Agricultural-related parcels were given a score of “10” because there is little activity occurring on these sites, but more than timberland. Mining-related sites were given a score of “5” because these sites are accessible, but mining activities may interfere with the recharge process. All other use types were given a “0” because there would be no control over site access. This scoring method gives suitability priority to locations that are within parcels that can have control over accessibility. This score vector file was converted to raster “Parcels_Score.gdb” to use in the final raster calculation to create the Site Suitability map.

3. **DOMESTIC WELLS** – Goal: Existing legal domestic use withdrawals no closer than 340.8-meters

The SRWMD permits the construction of water wells and drillers are required to submit a Water Well Completion Report upon completion, which includes the latitude and longitude location for the drilled well. The SRWMD had a limited spatial dataset that includes well locations. This dataset, “PermittedWells.shp” was used to determine areas where proximity to large numbers of domestic wells would be a concern (SRWMD, February 2018). Since domestic wells (wells serving single family homes) provide drinking water, care must be taken not to introduce any contaminants into existing drinking water wells. There is a likelihood that surface water contaminants, such as coliform, could be introduced into the aquifer from an AR well. Since DEP requires a recharge well owner have ownership or control of the property within 1,000 feet

(304.8 meters) of the well, a buffer was created around existing legal uses to avoid potential contamination. Since contamination of domestic wells can be somewhat controlled by constructing the AR well to a receiving zone deeper than the production zone of the domestic wells, this issue is not a significant concern when selecting a suitable site for the recharge well. Using the Union tool, the well buffer area was joined with the watershed area. This technique allowed the well buffer areas and non-buffer areas within the watershed to be scored. Since the likelihood of contaminating an existing domestic drinking water well is small, the well buffer areas were given a score of "-5". This score vector file was converted to raster "WellsScore.gdb" to use in the final raster calculation to create the Site Suitability map.

4. STREETS – Goal: Sites within 304.8 meters of streets with least public access

NAVTEQ provides GIS data for transportation types. The GeneralRoads2.shp file was provided by the SRWMD (NAVTEQ, February 2012). The streets available in this dataset are least traveled and includes private roads. It is the goal of this project to select a site that is not immediately accessible by the public to reduce any chances of vandalism. To keep consistent with other buffers used in this project, a 304.8-meter buffer was created around the low-use streets within the Hunter Creek watershed. The union tool was used to unite the buffer and watershed polygons. The buffer areas were then given a score of "20" to allow those locations to have higher priority in site suitability. Non-buffer areas were given a score of "0". This scoring method gives priority to suitability locations that are within 304.8 meters of a low-use street (i.e. not near high-use streets/highways) to reduce public accessibility and potential vandalism. This score vector file was converted to raster "Streets_Score.gdb" to use in the final raster calculation to create the Site Suitability map.

5. **RECHARGE** – Goal: Greatest head difference between land surface elevation and the potentiometric surface

The United States Geological Survey developed a potentiometric map in 2010 that covers the Hunter Creek basin (USGS, May 2010). This potentiometric map was developed from actual water level measurements within the Floridan aquifer. Then contours were interpolated across the study area using a raster calculator. To calculate the difference between the potentiometric surface and land surface elevation, LiDAR elevation data, which was available from SRWMD (”dem_huntercreek.tif”), was used (Digital Aerial Solutions, LLC. 2011). The LiDAR data was available from other sources; however, after many failed attempts it was determined the file for Hamilton County was so large that it was not feasible to use. SRMWD staff was able to provide the final DEM for Hunter Creek. Since the potentiometric map is a line vector file, the lines cannot be used to perform a calculation, the file was converted to a TIN file using the Create TIN tool. Then the TIN to Raster tool was used to create the final raster file that would be used to perform the calculation with the DEM file. The Raster Calculator tool was used to subtract the Potmap contours from the DEM, then the results were scored using the Reclassify tool making 5 classes using Natural Breaks to reclassify the range of results. The highest natural break group was given a “20” since those areas have the best potential for recharge. The other natural break groups followed the same rationale and the lowest natural break group was given a “0”. This scoring method gives priority to areas of higher recharge likelihood. This score vector file was converted to raster “PotDiffScore.gdb” to use in the final raster calculation to create the Site Suitability map.

6. **TRANSMISSIVTY** – Goal: Highest aquifer transmissivity

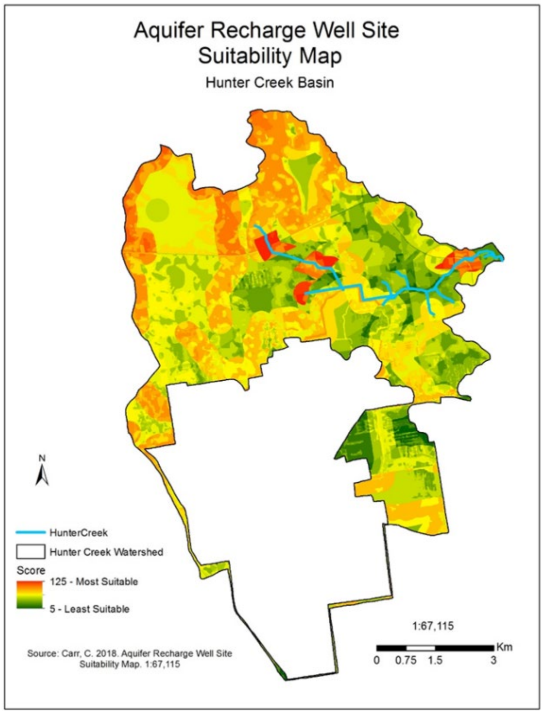
To determine the transmissivity within the UFA several files from the Northeast Florida Southeast Georgia (NFSEG) Model version 1.1 (props_bottom_elevation.shp, props_hydraulic_conductivity.shp, and props_top_elevation.shp) were used to calculate the transmissivity of the UFA across the Hunter Creek basin (NFSEG, 2018). Transmissivity is a product of the thickness of an aquifer and the hydraulic conductivity. To calculate the thickness, the tops and bottoms of each layer within the Floridan aquifer were used. Within each shapefile there are several layers listed. These layers represent the different aquifer zones within the NFSEG model. Layer one is the surficial aquifer system. Layer two is the intermediate confining unit. Layers three through five (used in the calculation of Floridan aquifer thickness) represent the layers of the Florida aquifer in the NFSEG model. Since the data was already in raster files, the Raster Calculator tool could easily do all the calculations. Once the transmissivity was determined for each layer, the transmissivities were then added together using the Raster Calculator tool. The final raster file showed the range in transmissivity across the Hunter Creek basin. To create the score file needed to produce the final Suitability Map, the ranges were divided into 5 classes using Natural Breaks with the highest transmissivities having a score of "20" and the lowest transmissivities having a score of "0". This scoring method gives priority to suitability locations that have highest transmissivities to allow for better movement of water into the aquifer. The final score file "T_Score.gdb" was used in the final raster calculation to create the Site Suitability map.

7. **LOCATION** – Goal: highway access allowing easier access for well drilling rig (highway 304.8-meter buffer) and near Hunter Creek (304.8-meter buffer)

The road files used in the development of the location score (GeneralRoads.shp, CountyRoads.shp, and MajorRoads.shp) were provided by SRWMD staff; however, the data source is NAVTEQ (NAVTEQ, February 2012). The priority of the site suitability map is to determine the most suitable locations for recharge wells adjacent to Hunter Creek. To reduce the amount of piping needed to convey water from the creek to the recharge well, the recharge well should be close to the creek. The site also must be accessible by major roads to allow large equipment onto the site. To find ideal locations, a 304.8-meter buffer (to keep consistency with other setbacks and buffers) was created around major roads and Hunter Creek. Then the areas intersecting those buffers were isolated and given a score of “50”. The highest value was given to these locations so that the suitability map would easily show these locations are best. See Flow Chart 7 for specific methods used to create the final raster, Streets_Score.gdb.

Final Raster Calculation – Goal: Add all scores together

Finally, Since the scores were already assigned successfully to each parameter by following Methods 1 through 7, the final raster calculation produced the Site Suitability Map. See Flow Chart 8 for the summary of score raster files created and the final suitability map. Scores of 125 were determined to be the most ideal location for the proposed recharge well.



Source: Carr, C. 2018. Aquifer Recharge Well Site Suitability Map. 1:67,115

Figure 1. Hunter Project Site Suitability Map

HUNTER PROJECT CONCLUSION

The scoring of each parameter allowed for an overall calculation which determined a locations suitability map. Final site suitability scores ranged from 0 to 125 with 125 (shown as red) being a prime location for the construction of the proposed AR well. An unexpected observation in the Hunter Project was that recharge scores were higher at locations furthest from Hunter Creek. These results are likely due to higher land surface elevations farther from the creek. Since the UFA's potentiometric levels across the Hunter Creek basin only ranged 10 feet (3 meters), the potentiometric surface component of the evaluation did not affect the score as much as anticipated.

The transmissivity score also did not change appreciably across this basin due to limited aquifer performance tests completed in the study area ; however, like the potentiometric surface, the transmissivity remains a valuable component when comparing sub-basins. The scale for Hunter Project was likely too fine for the transmissivity data and staff should consider doing a site suitability map for the entire basin and compare results for each sub-basin. Even though there are improvements to be made, the GIS-based scoring and raster calculation method proved to be an invaluable time-saving evaluation tool since it lays out the framework for future evaluations of other watersheds.

It was also expected that the buffers and scores for streets and highways would heavily skew locations near major roads and Hunter Creek, but it was apparent that the other criteria and scores affected the overall raster calculation within those areas (i.e. it was expected the red areas would dominate the sites nearest to the highways and Hunter Creek, but some of those areas actually had a lower final score). The buffers should be reevaluated in future projects to see if some areas could be excluded from the suitability map altogether. Since areas too far from the creek and on private lands would not even be considered due to project costs, those areas could be excluded completely from the process.

The suitability scores for the Hunter Project provided a range that should allow SRWMD staff to select a location for the construction of a recharge well using a method that rapidly considers several variables and is reproducible for future projects; however, the arbitrary scoring method could be improved. The Hunter Project also included important aquifer characteristics that may have affected the results of the HSW Project. The HSW Project included important watershed characteristics including water available for use and water quality data that could have affected the Hunter Project results had they been considered. Each project offered considerations that should be used in future site selection projects.

AMINEH PROJECT

Amineh et al. completed a GIS-based site suitability project to identify the ideal location in the Toghrodd watershed in the Ghom province of Iran for an ASR well. As groundwater levels have declined in the Harmoon-Jazmoorian plain, serious problems such as land subsidence and water quality degradation could be reduced if ASR wells could be used to divert surface waters into the aquifer. Although the target aquifer properties needed for an ASR well are different than those needed for an AR well (because the target aquifer must be able to store the water), other criteria evaluated for the ASR well site are similar to the criteria used for the AR well site. An ASR well is used to inject water into an aquifer so that the water can be pumped back out when the normal source of water cannot meet demand. The aquifer used for an ASR well must have a transmissivity rate that is low. In contrast, an AR well is used to inject water into the aquifer and is not later recovered.

Amineh et al. implements an Analytical Hierarchy Process (AHP) to assign weights to different criteria. The brief summary of the AHP process includes creating a hierarchy of decision-making elements, completing pairwise comparisons and comparison matrices, deriving local and global priorities, and applying a consistency check. The initial decision-making process includes prioritizing criteria by qualitatively assigning weights. Nine criteria were identified in the decision matrix. These criteria were then scored for importance via a survey of hydrogeologists and geologists. The criteria were then used in a comparison matrix to determine comparison weights (Table 2), and a final site suitability map (Appendix Figure E) was created.

Criteria	Score range (suitability index)
Source and groundwater compatibility	0.021 - 0.770
Source water quality	0.040 - 0.532
Storage availability (depth to the potentiometric surface)	0.047 - 0.591
Groundwater quality (electrical conductivity)	0.070 - 0.639
Construction cost (distance to existing wells)	0.068 - 0.770
Source water availability (runoff height)	0.040 - 0.532
Aquifer characteristics (transmissivity)	0.068 - 0.770
Demand (water level decline)	0.040 - 0.532
Operation Cost (possibility of gravity transmission)	0.100 - 0.900

Table 2. Amineh et al. scoring matrix

The Amineh project did not include considerations for site accessibility and property ownership. Although Amineh pointed out that similar projects considered accessibility and ownership, the literature offered no explanation why it was not used as criteria. Possible explanations could be no limit to project costs or possible political processes that allow the optimal site to be used for the well location. While the Amineh project did not consider accessibility or ownership, both the HSW Project and Hunter Project used arbitrary ranking systems instead of conventional multi-criteria decision making techniques. Had those projects used AHP process for ranking criteria, they may have had different results.

SMITH PROJECT

Smith et al. completed a GIS-based site suitability project to identify the sites where ASR wells would be most successful in two aquifer systems (Carrizo-Wilcox and Gulf Coast) located in Texas. As these areas face water shortages, ASR wells are a viable option for storing water during high intensity storms so that water demands can be met during long periods of drought. The highest transmissivity is not most desirable since the goal of ASR is to inject water but later recover it; therefore, the transmissivity in this study was relatively ranked 1 through 4, with 4 being most desirable transmissivity in a middle range (Table 3). In this study, five hydrogeologic criteria were used and scored (Table 4). Other criteria were not used based on scale and inconsistent social and regulatory factors. Final site suitability maps were produced to identify areas where ASR wells are most feasible (Figure 2).

Transmissivity (m^2/day)	
Class	Score
0-230	1
230-700	2
700-1160	3
1160-1630	4
1630-2550	2
2550-3950	1
>3950	

Table 3. Transmissivity ranking

Criteria	Score range
Transmissivity (m^2/d)	1-4
Hydraulic gradient	1-4
Density of existing wells	1-4
depth to potentiometric surface	1-3
depth to the top of the aquifer	1-3

Table 4. Smith et al. scoring matrix

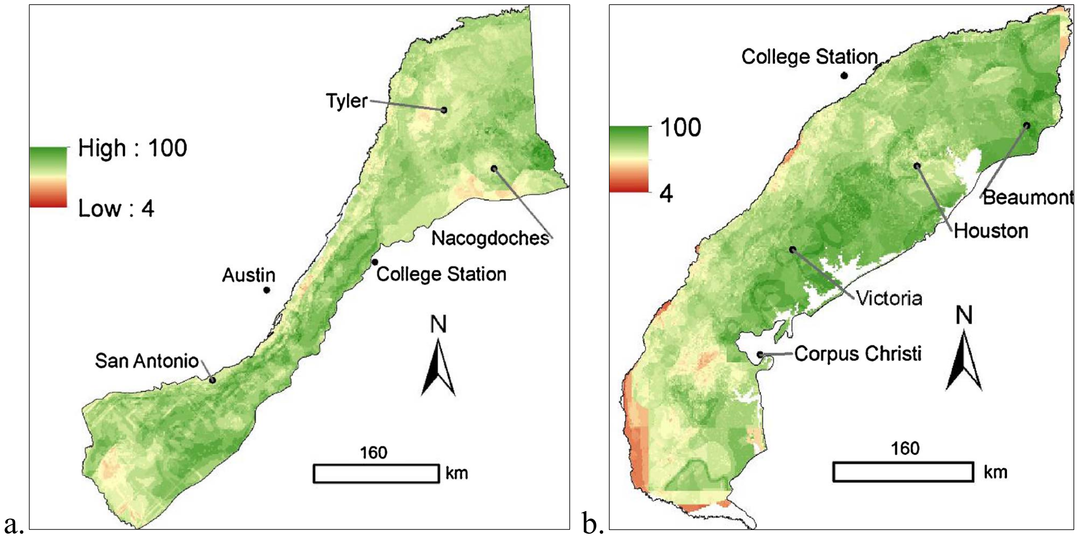
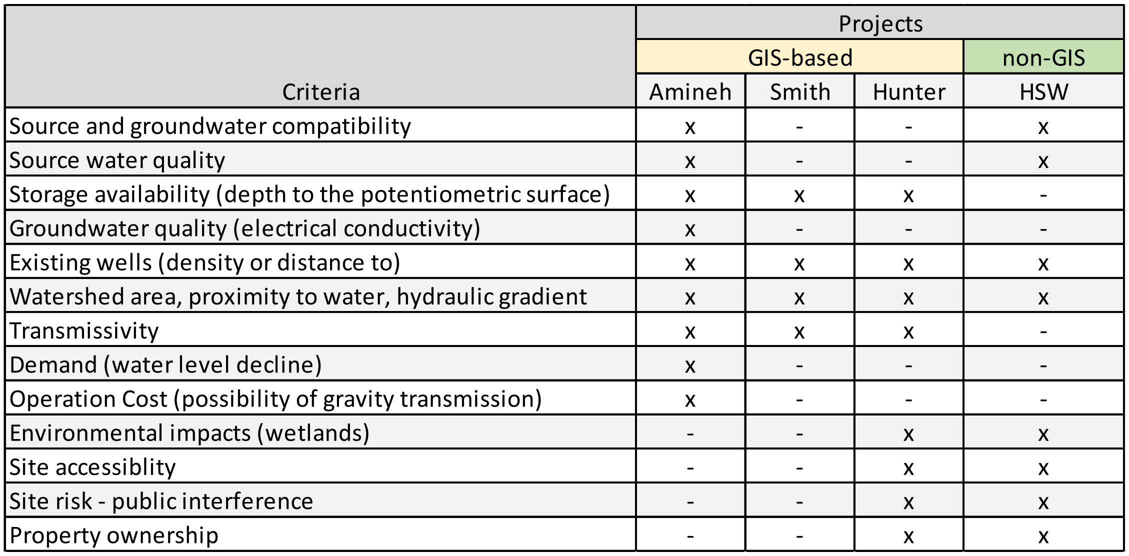


Figure 2. Smith et al. Site suitability maps.
a. Carrizo-Wilcox aquifer system b. Gulf Coast aquifer system

Sites with mid-range transmissivity values are most desirable for the Smith Project since the goal of the ASR project is to inject water into the aquifer so that it can be pumped back out for later use. It is ideal to identify the sites where transmissivity data is available and choose sites where transmissivity is optimal. Transmissivity must be a consideration for all ASR or AR projects since a low transmissivity could prevent project success for any ASR or AR well and a high transmissivity could prevent project success for an ASR well. The aquifer material composition can greatly influence the transmissivity and significantly affect the success of a project.

DISCUSSION

A final criteria comparison was made to determine consistency in criteria used in site suitability selection for all projects. It is apparent through this comparison exercise that no two projects are consistent except for the consideration given to existing well users and the watershed area considerations; however, the watershed area considerations were from different data sources based on what was available. The actual size of the watershed area was considered in Amineh et al and HSW (to evaluate the water available for the project), but Smith et al. focused on hydraulic gradient (greater elevation differences) and the Hunter project focused on distance to source water (an arbitrary buffer to the creek).



	Projects			
	GIS-based			non-GIS
Criteria	Amineh	Smith	Hunter	HSW
Source and groundwater compatibility	x	-	-	x
Source water quality	x	-	-	x
Storage availability (depth to the potentiometric surface)	x	x	x	-
Groundwater quality (electrical conductivity)	x	-	-	-
Existing wells (density or distance to)	x	x	x	x
Watershed area, proximity to water, hydraulic gradient	x	x	x	x
Transmissivity	x	x	x	-
Demand (water level decline)	x	-	-	-
Operation Cost (possibility of gravity transmission)	x	-	-	-
Environmental impacts (wetlands)	-	-	x	x
Site accessiblity	-	-	x	x
Site risk - public interference	-	-	x	x
Property ownership	-	-	x	x

Figure 3. Criteria comparison

Some of the listed criteria may need to be reconsidered depending on available data, aquifer material composition, ASR vs AR, and scale. For instance, if the study area is a small watershed with homogeneous transmissivity in the aquifer, then there would be no advantage in considering the transmissivity; however, if several watersheds are being considered and each watershed had a different transmissivity, then transmissivity would be a factor affecting the final site suitability score. The different composition material of the aquifer is a very important consideration. If the material does not allow movement of water (low or no transmissivity), then ASR and AR will not work because the water cannot be injected. If the material allows too much movement of water (high transmissivity), then the water will move too quickly away from the proposed storage site and cannot be recovered for later use. Using the listed criteria will provide guidance for the type of data needed.

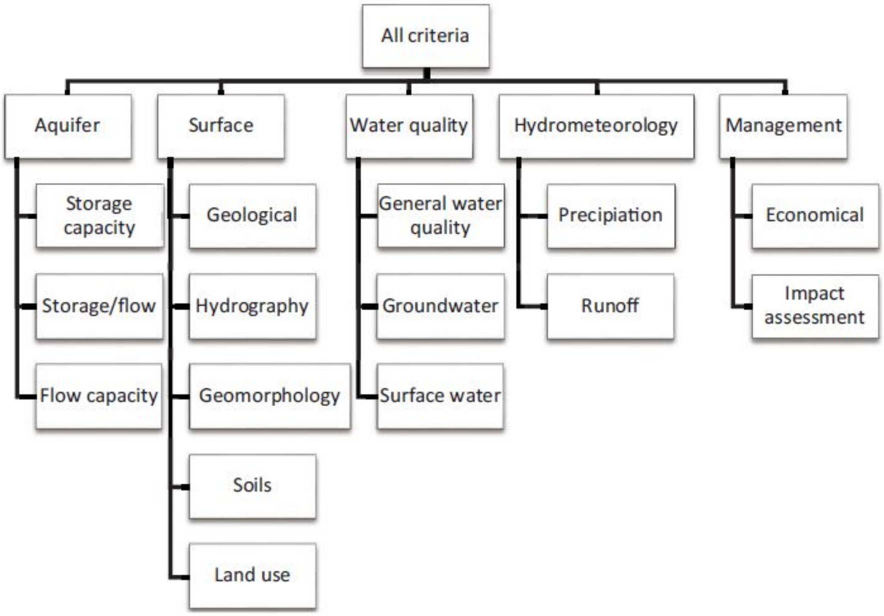


Figure 4. Sallwey criteria summary

Sallwey et al. completed a review of 63 multi-criterion decision analysis studies and summarized the criteria used in Figure 4. Comparing these criteria to those summarized in Figure 3 shows the same criteria are considered; however, all projects may not be able to evaluate every criterion for several reasons. The most common reason a criterion is not considered is unavailable GIS data. The criteria shown in Figure 3 can fit into the categories shown in Figure 4 except for demand. Demand is more appropriately used for ASR projects instead of AR projects due to the need to pump out the stored water when demand increases.

Sallwey et al. also presented a summary of the weighted ranking logic used in the 63 studies (Figure 5). The Hunter Project and HSW Project used a ranking method that was arbitrary. The Amineh Project used the Analytical Hierarchy Process (AHP) method of ranking and the Smith Project used a relative ranking system which was also arbitrary. According to Sallwey et. al, the most used weighted ranking logics were the Weighted Linear Combination (WLC) and Analytic Hierarchy Process (AHP) which is a type of WLC.

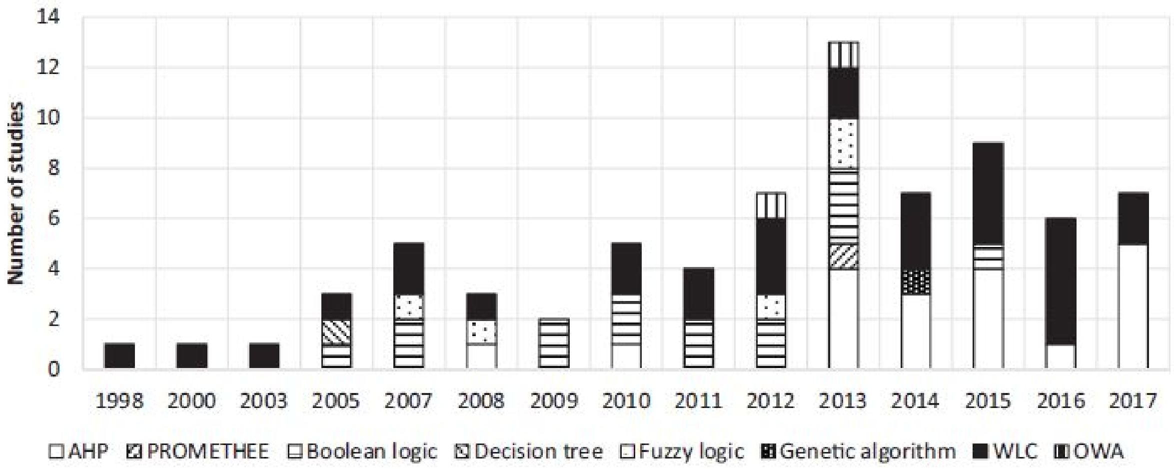


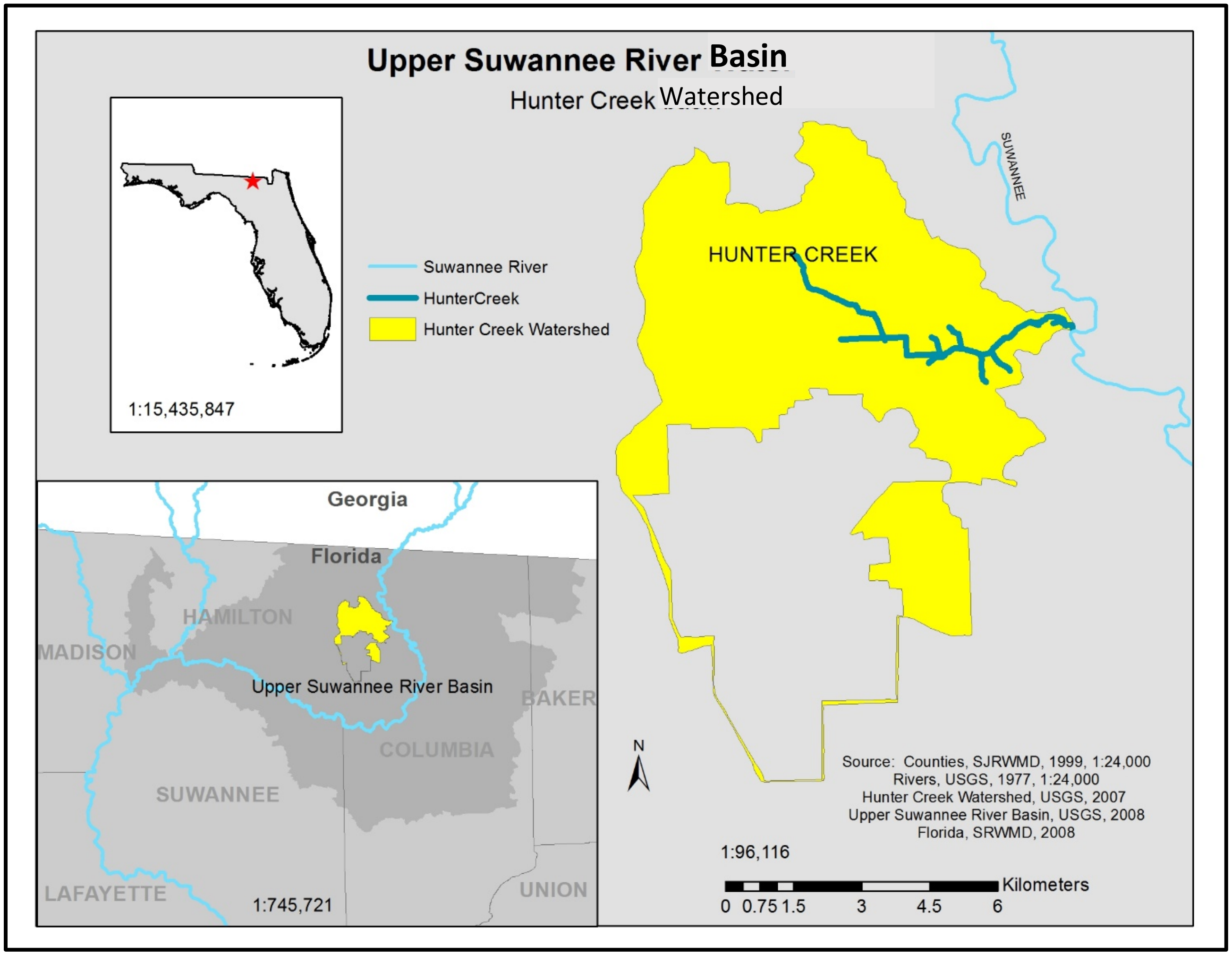
Figure 5. Sallwey weight assignment methods

Sallwey et al. also found 14 of the 63 studies performed a sensitivity analysis. The most common method for completing a sensitivity analysis is to change the weights of the criteria and run the analysis again with each iteration of weights and the resulting suitability maps compared with the base map. If the difference between the maps were minimal, then the assigned weights were assumed to be appropriate. None of the projects or papers presented in this paper completed sensitivity analyses.

CONCLUSIONS

The evaluation of these scoring methods suggests the criteria shown in the Figure 4 should be used as the list of data needed to conduct a GIS-based site suitability selection project for future selection of aquifer recharge well sites. Failure to consider all criteria may likely lead to the selection of a site that could cost more (if site conditions are unknown and heavy machinery is damaged), be more hazardous (if source water quality is not understood), cause undue harm to existing users (if injected water changes the water quality for existing users), not function properly (if there is no significant depth to potentiometric surface, then there will likely be no water movement into the aquifer). If data is not available for every criterion, then water managers would need to consider collecting the data. If water managers consider all criteria in a consistent, reproducible, GIS-based approach, a suitable site may be selected for AR wells. A weighted ranking logic like WLC or AHP should be used to determine the weighted ranks of each criteria, and a suitability analysis should be run to evaluate the appropriateness of weighted criteria. While the Hunter Project determined the framework for GIS-based site selection tool for the SRWMD, the District should consider running the same analysis for all sub-basins within the Upper Suwannee River Basin to determine which sub-basin would be best. The analysis should follow the WLC or AHP for determining the weights of the criteria and a sensitivity analysis should be considered.

APPENDIX



Source: Counties, SJRWMD, 1999, 1:24,000
Rivers, USGS, 1977, 1:24,000
Hunter Creek Watershed, USGS, 2007
Upper Suwannee River Basin, USGS, 2008
Florida, SRWMD, 2008

Figure A. Upper Suwannee River Watershed and Hunter Creek Basin

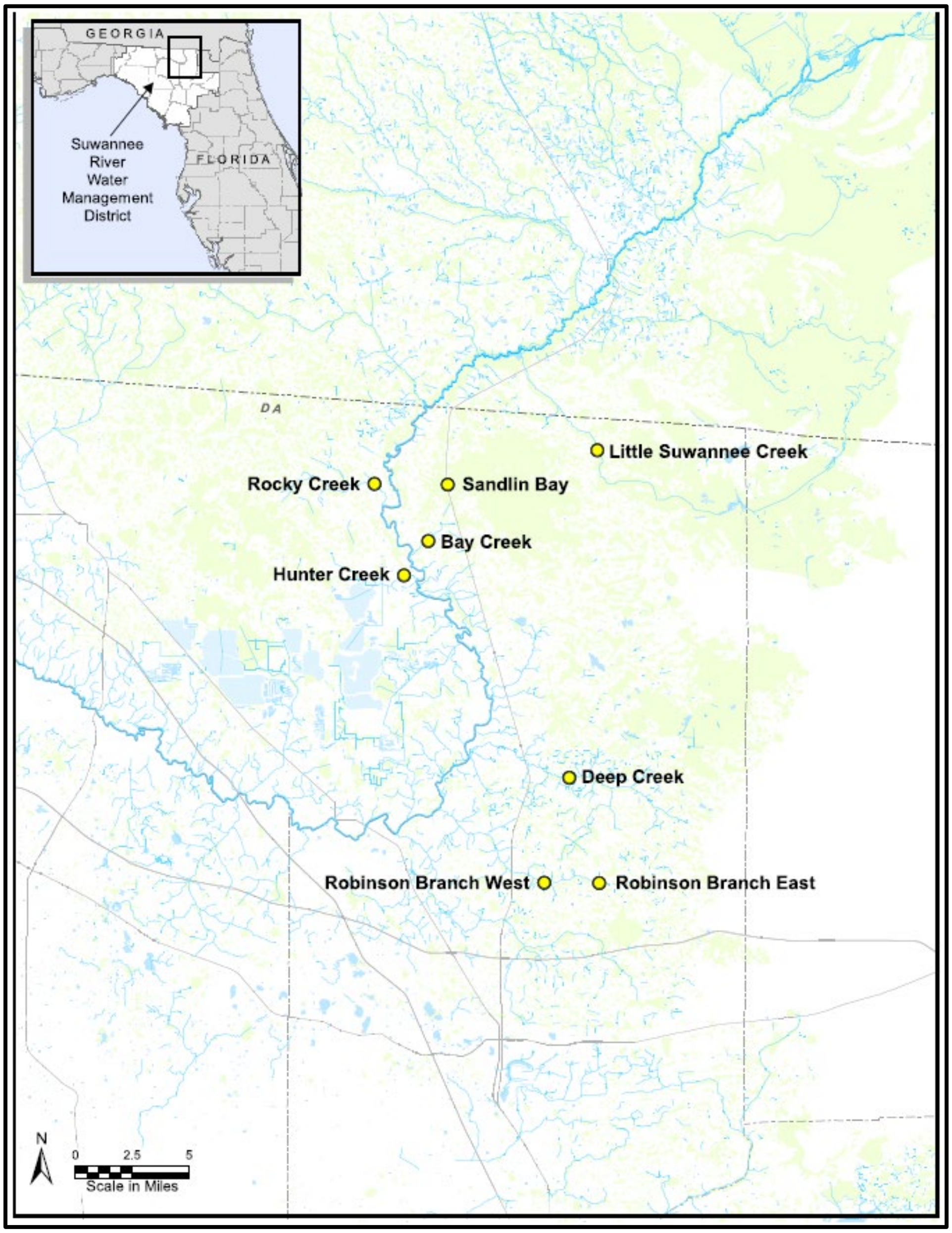


Figure B. HSW Project Potential Well Sites (HSW, 2018)

Score	Criteria Ownership/Control		Construction/Permitting		Available Water for Capture		Water Quality		Other	
1	Well site on District land	no wells within 1000 ft	Accessbile for drilling equipment	Minimal clearing	Potential capture > 2 MGD	Gage on tributary	No exceedeance	WQ data availble from gage at potential well site	Private land, locked access	No issues identified
2	One land owner within 1000 ft	Potential well within 1000 ft	Some fill and clearing at well site	Need to cross wetland/floodplain	Potential capture < 2 MGD	No gage on tributary	Exceeds Al, Fe, Color, Coliform	WQ data available from tributary	Evidence of activity at site	Potential issue
3	Multiple land owners within 1000 ft	UFA well within 1000 ft	Difficult access	Wide shallow floodplain, clearing may be needed for construction	-	-	Additional exceedances	No previous WQ data available	Evidence of heavy activity at site	Multiple potential issues identified

Figure C. HSW Project Scoring matrix

	Ownership/Control		Construction/Permitting		Available Water for Capture			Water Quality		Other		Score	
Potential Well Site	Property Ownership within 1000ft	Potential for wells within Zone Of Discharge	Access for well construction	Floodplain and Intake access	Screening analysis potential annual average capture (MGD) / Watershed area above potential well site (mi^2)	Gage on tributary	Proximity to USR (miles)	Water Quality - 2018 sample event	WQ data available	Local activity	Other	Sum	Sum of Avg for each Category
Hunter Creek	1	2	1	1	2	1	1	2	1	2	2	16	7.3
Rocky Creek	2	1	1	1	1	1	1	2	1	3	1	15	7
Deep Creek	2	1	1	2	1	1	2	2	2	2	1	17	7.8
Bay Creek	2	1	3	2	2	2	1	2	3	1	1	20	9.2
Robinson Branch West	2	1	1	2	2	1	2	2	2	2	1	18	8.2
Sandlin Bay (Bay Creek)	3	1	1	2	2	2	2	2	3	2	2	22	10
Robinson Branch East	2	1	3	2	2	1	3	2	2	2	2	22	10
Little Suwannee Creek	1	1	3	3	1	2	2	2	2	2	3	22	10.2

Figure D. HSW Project Scored criteria

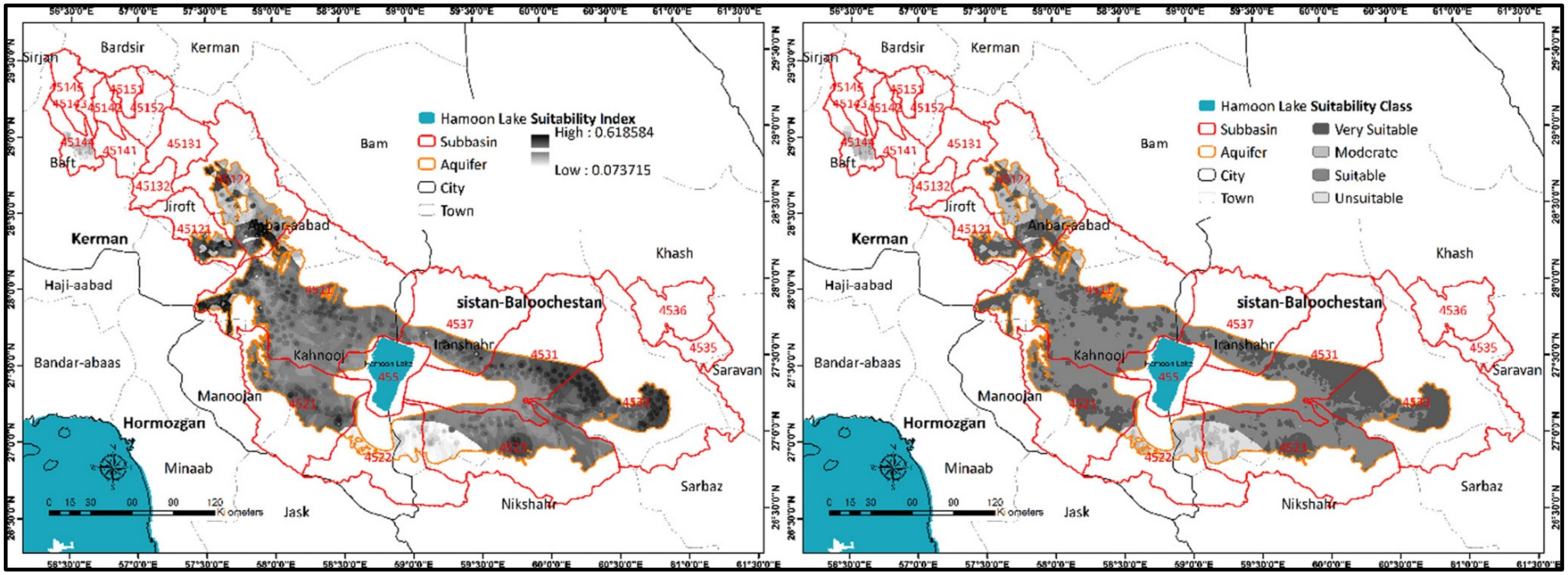
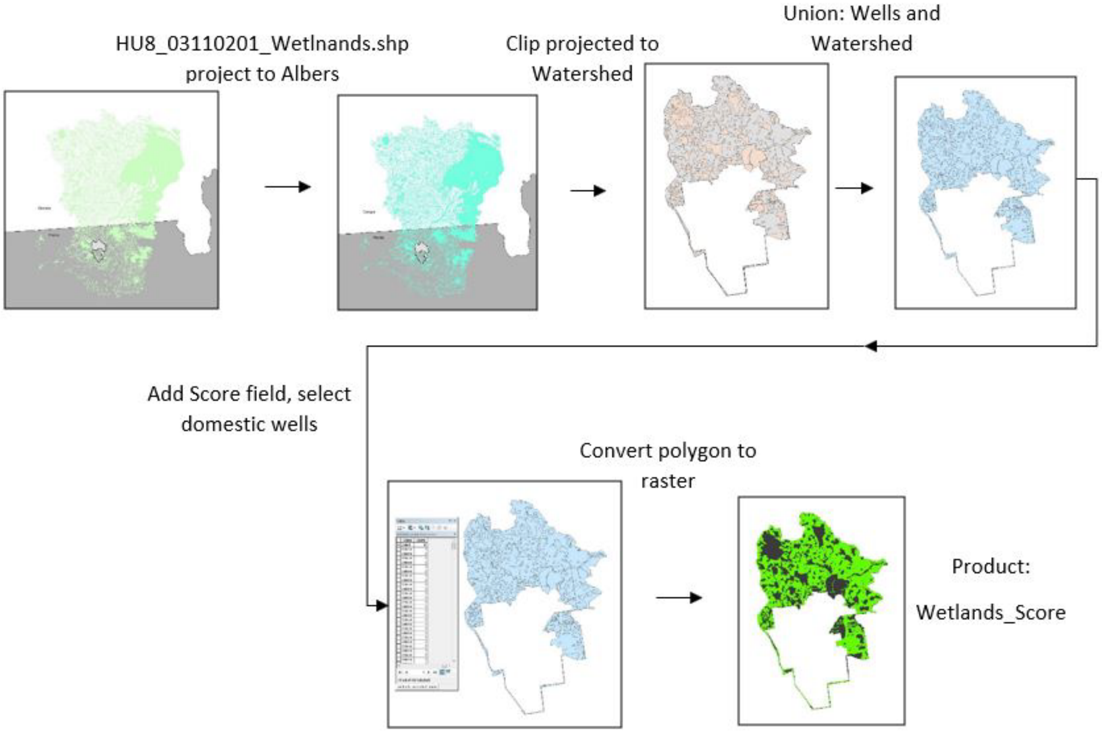
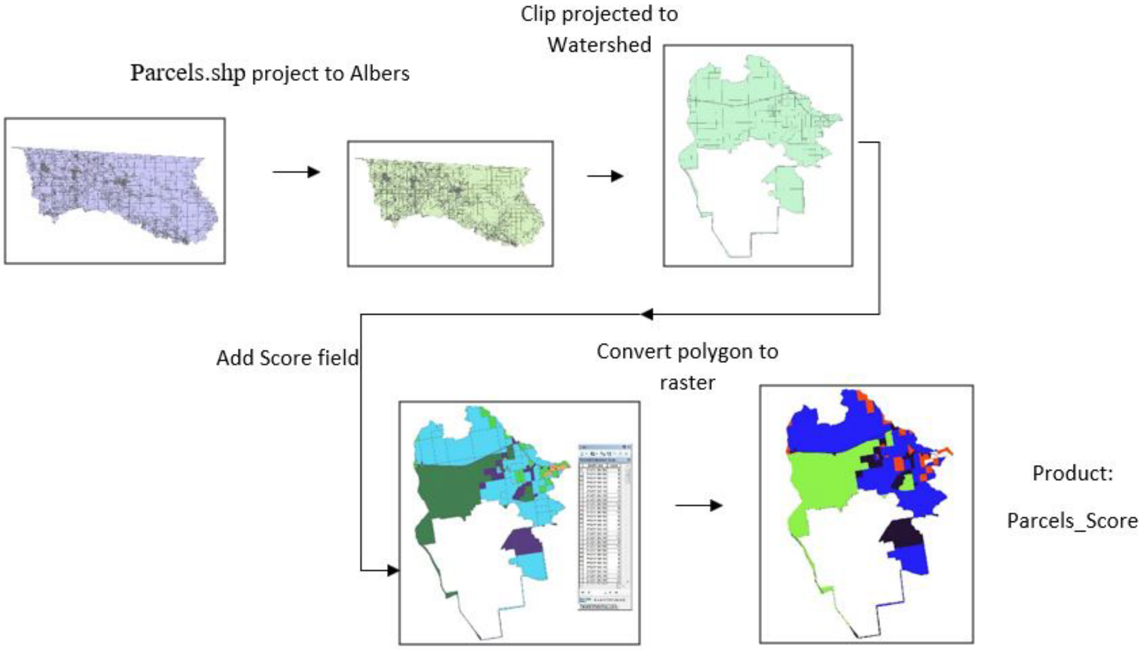


Figure E. Amineh et al. Site Suitability Maps

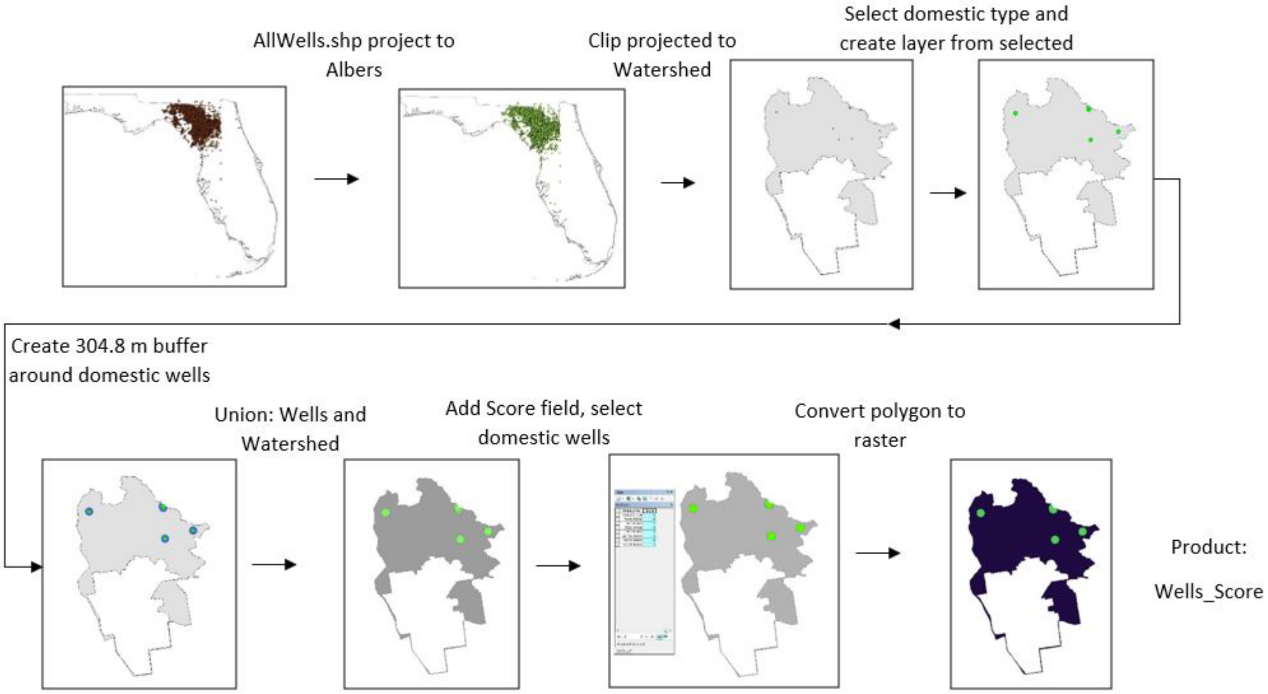
Flow Chart 1: Wetlands Score



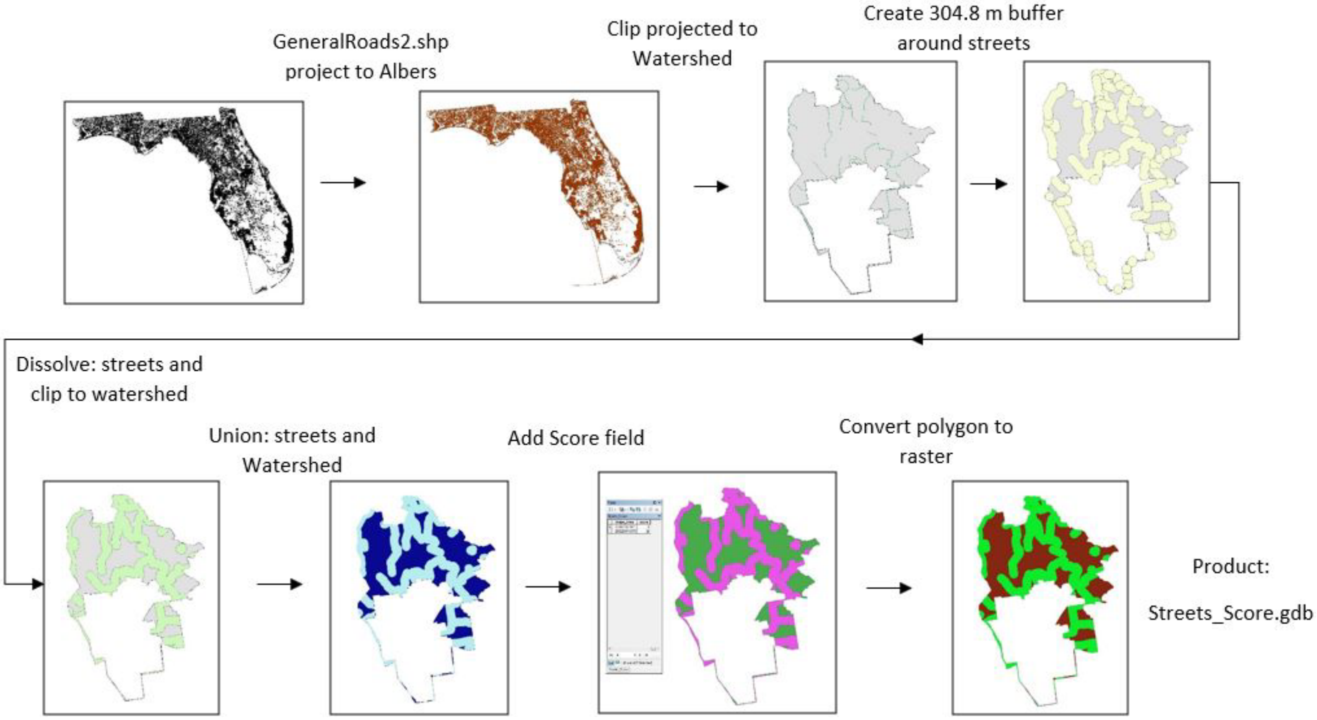
Flow Chart 2: Parcel Score



Flow Chart 3: The distance from existing legal domestic use withdrawals from the UFA is greater than 340.8 meters



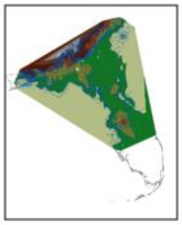
Flow Chart 4: Street access allowing least vandalism (304.8 m)



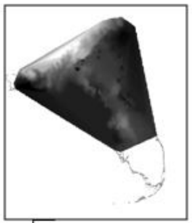
Flow Chart 5: The difference between land surface elevation and the potentiometric surface of the UFA is highest

Potmap_contours_May2010

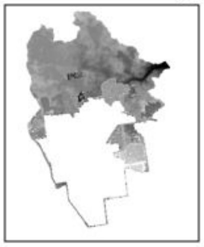
Create TIN



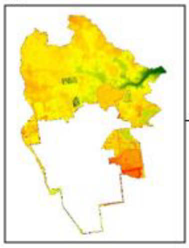
TIN to Raster



Dem_huntercreek.tif

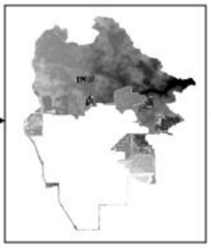


project to Albers



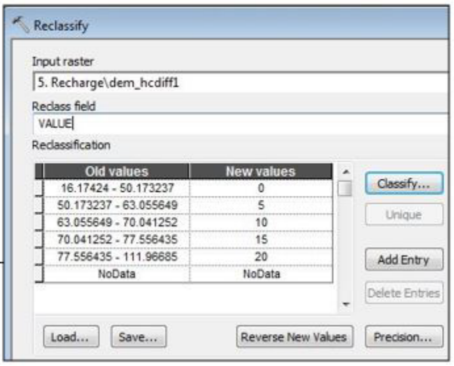
Raster Calculator:

Potmap – DEM_hungercreek.tif = dem_hcdiff1



Reclassify

dem_hcdiff1



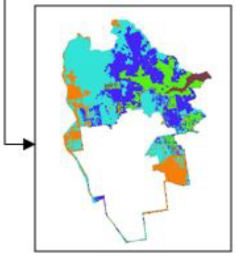
Reclassify

Input raster: 5. Recharge\dem_hcdiff1

Reclass field: VALUE

Reclassification

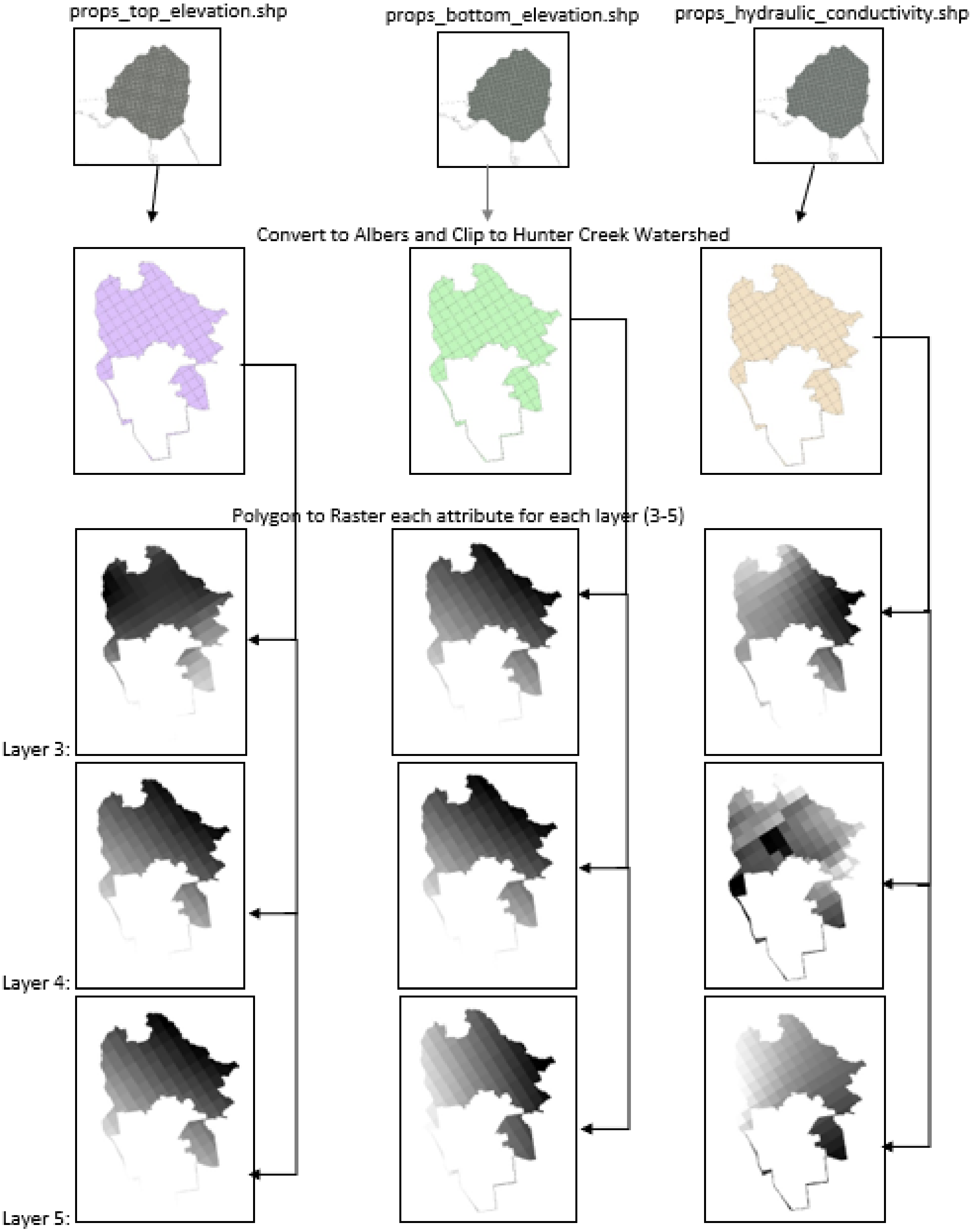
Old values	New values
16.17424 - 50.173237	0
50.173237 - 63.055649	5
63.055649 - 70.041252	10
70.041252 - 77.556435	15
77.556435 - 111.96685	20
NoData	NoData



Product:

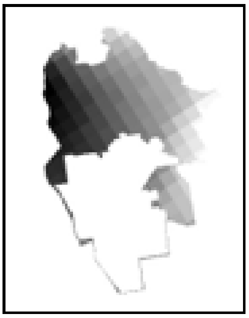
Recharge_Score.gdb

Flow Chat 6: The UFA transmissivity is highest

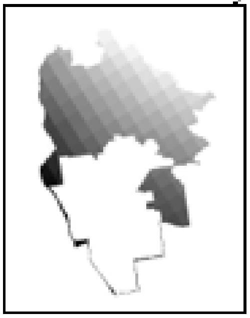


Use Raster Calculator to determine the thickness of each layer:

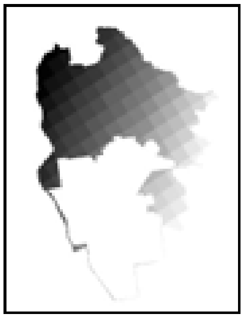
Layer 3:



Layer 4:

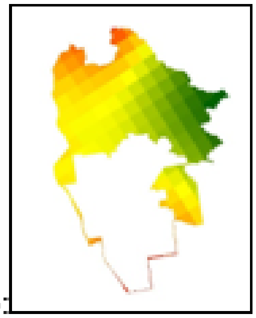


Layer 5:

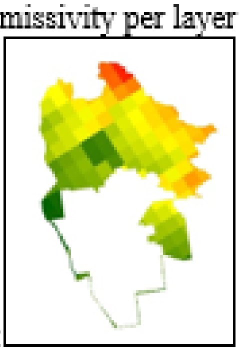


Use Raster Calculator to determine Transmissivity per layer (thickness * hydraulic conductivity):

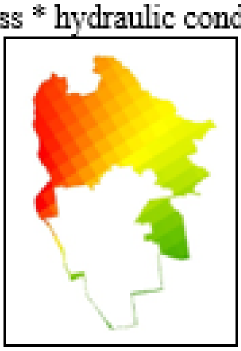
Layer 3:



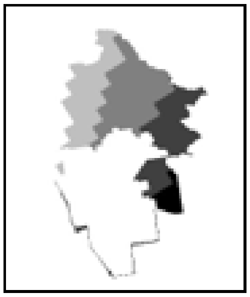
Layer 4:



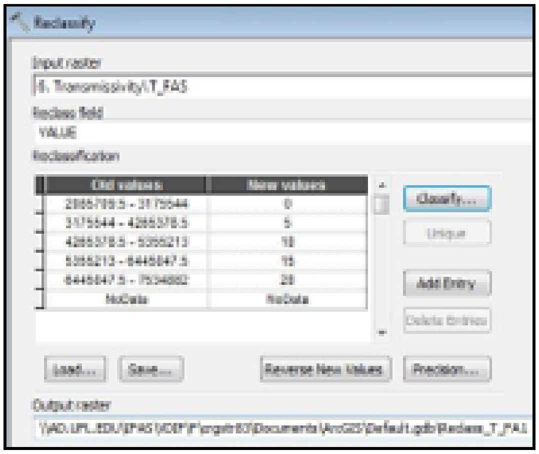
Layer 5:



Use Raster Calculator to determine Transmissivity of UFA (add T for all layers):



Reclassify the layer:



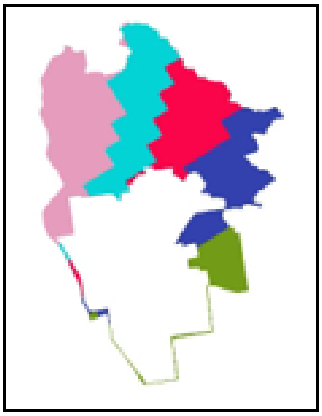
Input raster: 6. Transmissivity\T_FAS

Reclass field: VALUE

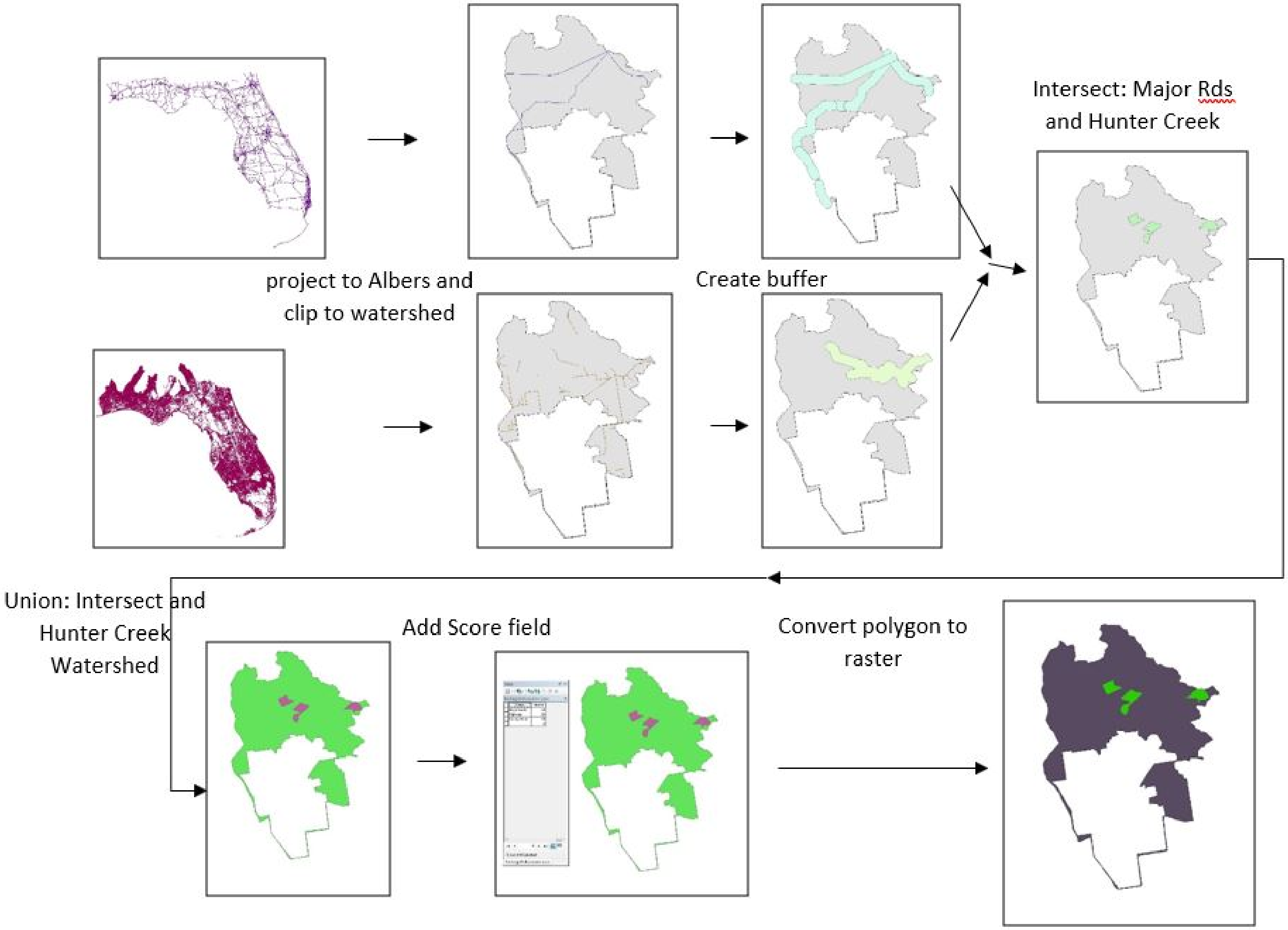
Reclassification

Old values	New values
2085709.5 - 3175544	0
3175544 - 4265378.5	5
4265378.5 - 5355213	10
5355213 - 6445047.5	15
6445047.5 - 7534882	20
NoData	NoData

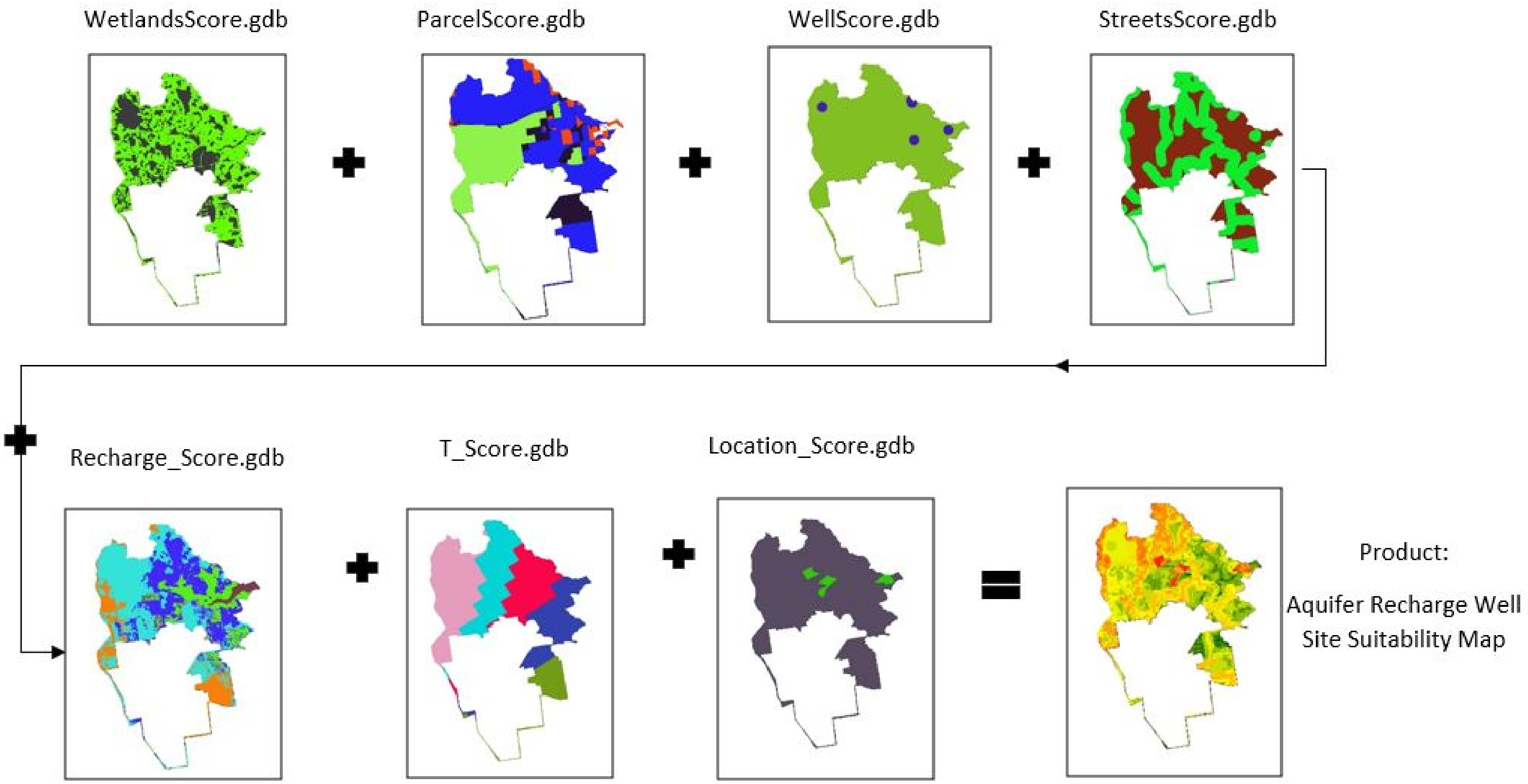
Output raster: \\AD.UFL.EDU\IFAS\IOEP\F\prgstr83\Documents\ArcGIS\Default.gdb\Reclass_T_FA



Flow Chart 7: highway access allowing easier access for well drilling rig (304.8 m) and near Hunter Creek (304.8m)



Flow Chart 8: Final Raster Calculation



REFERENCES

Amineh, Z. Hashemian, S. Magholi, A. Integrating Spatial Multi Criteria Decision Making (SMCDM) with Geographic Information Systems (GIS) for delineation of the most suitable areas of aquifer storage and recovery (ASR). Journal of Hydrology. Vol. 551. 2017. pp 577-595.

Digital Aerial Solutions, LLC. 2011. Suwannee River Bare Earth DEM. Available at: http://www.fgdc.gov/metadata/fgdc-std-001-1998.dtd

Hamilton County Property Appraiser. April 26, 2018. Hamilton County Parcels. Available at: http://qpublic.net/fl/hamilton/mapdata.html

HSW Engineering, Inc. 12 December 2018. Upper Suwanee River Regional Aquifer Recharge Project: Pre-Design Study.

NAVTEQ. February 10, 2012. NAVTEQ NAVSTREETS. Available at: http://NAVTEQ.com

North Florida Southeast Georgia Groundwater Model (NFSEG V1.1), 2018, Durden D, Gordu F, Hearn D, Meredith L, Angel A, and Grubbs T, Available at: https://northfloridawater.com/pdfs/NFSEG/TaskD/NFSEGv1.1_rev2018_0507.pdf

Sallwey, Jana. Bonilla Valverde, Jose. Vasquez Lopez, Felipe. Junghanns, Ralph. et al. Suitability Maps for Managed Aquifer Recharge: A Review of Multi-Criteria Decision Analysis Studies. Environmental Reviews. 2019, 27(2). pp 138-150.

Smith, Benjamin. Miller, G. Sheng, Z. Assessing aquifer storage and recovery feasibility in the Gulf Coastal Plains of Texas. Journal of Hydrology: Regional Studies. Vol. 14. 2017. pp 92-108.

Suwannee River Water Management District. March 2011. Request for Qualification No. 10/11-022WR Upper Florida Aquifer Regional Recharge Concepts.

Suwannee River Water Management District. 2015. Watersheds (Basins) – SBAS Coverage.

Suwannee River Water Management District. February 2018. SRWMD Permitted Well Locations.

United States Fish and Wildlife Service. 2017. Wetlands and Deepwater Habitats of the United States. Available at: http://www.fws.gov/wetlands/data/Data-Download.html

United States Geological Survey. May 2010. Potentiometric Surface of the Upper Floridan Aquifer in Florida and in Parts of Georgia, South Carolina, and Alabama.

United States Geological Survey. The National Hydrography Dataset (NHD). 2010.