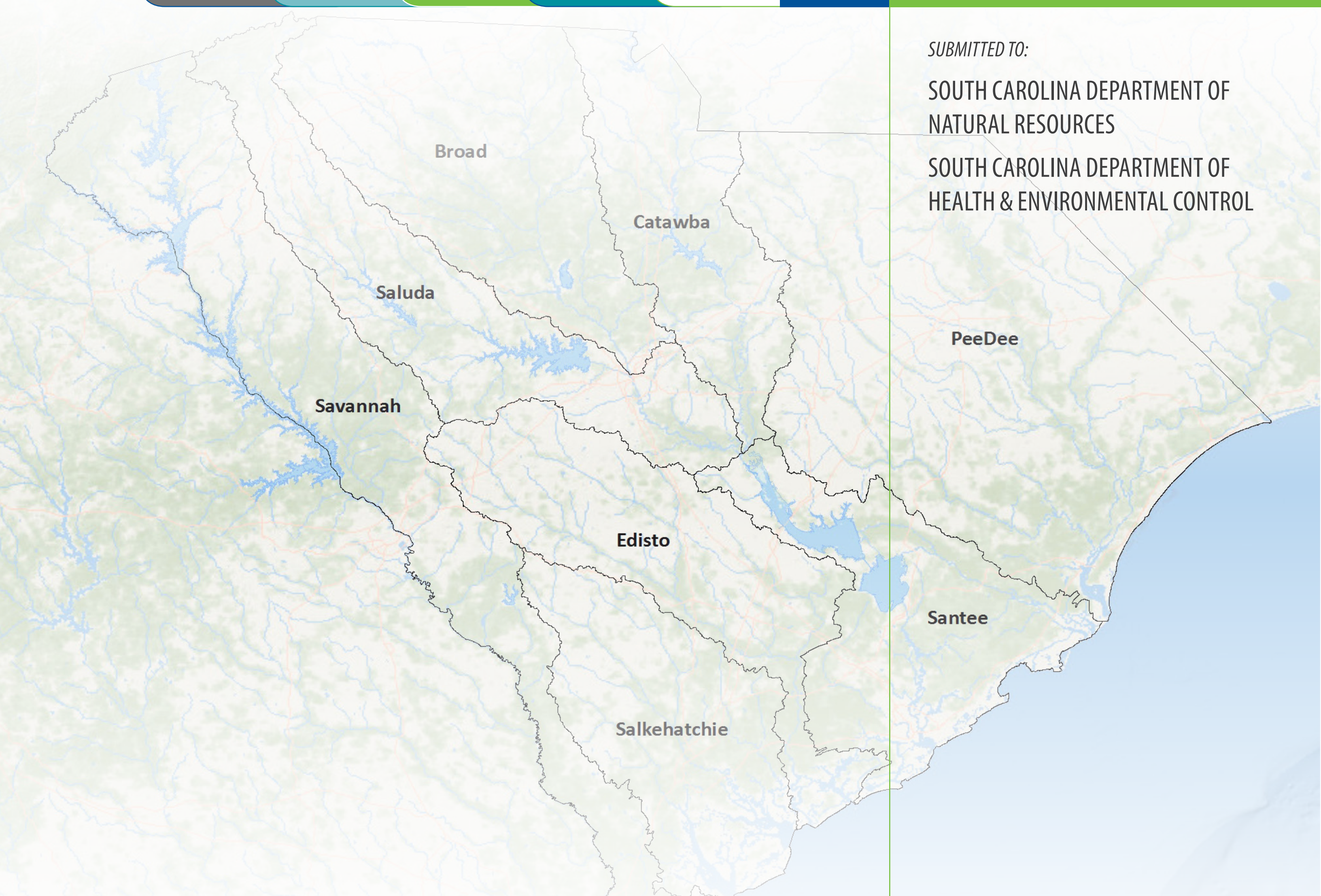
SOUTH CAROLINA SURFACE WATER QUANTITY MODELS MODELING PLAN

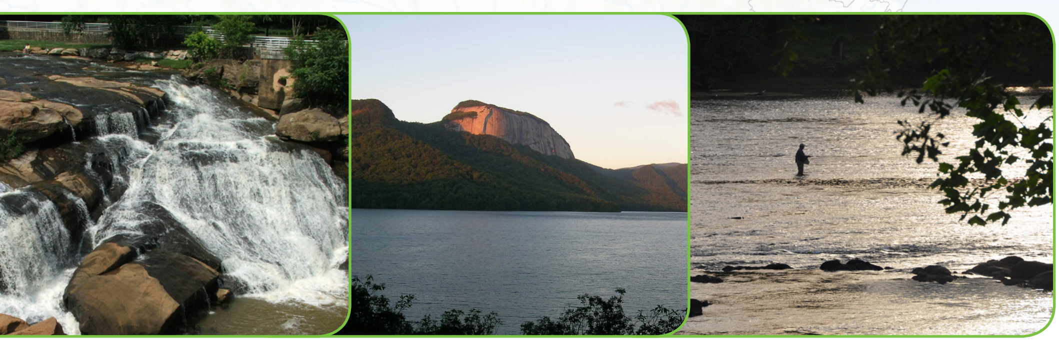


SUBMITTED TO:

SOUTH CAROLINA DEPARTMENT OF NATURAL RESOURCES

SOUTH CAROLINA DEPARTMENT OF HEALTH & ENVIRONMENTAL CONTROL

NOVEMBER 2014



PREPARED BY:

CDM Smith

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Section 1

Purpose

This document is provided in support of the development of Surface Water Quantity Models for the South Carolina Department of Natural Resources (DNR) and the South Carolina Department of Health and Environmental Control (DHEC). The models are being developed as part of a broader strategy to update statewide water planning tools and policies. The models are primarily intended to represent the impacts of water withdrawals, return flows, and storage on the water quantity throughout each major river basin in the state. With this ability, they will be used for regional water planning, policy evaluation and permit assessments.

This Modeling Plan is an overarching approach, intended to guide the development of River Basin Models for South Carolina by describing consistent procedures, guidelines, and assumptions that will apply to each basin and model. It is not an exhaustive step-by-step procedure for developing a model in SWAM (for this level of detail, a User's Manual is provided), nor does this address all of the specific issues that may be unique to particular basins. Rather, this Modeling Plan offers strategic guidelines aimed at helping model-development staff make consistent judgments and decisions regarding model resolution, data input, and representation of operational variables and priorities.

Additionally, this document is intended to help disseminate the information about how the models will represent the river basins in South Carolina to parties with a vested interest in water management (stakeholders). To this end, the language is intended to be accessible and explanatory, describing the model development process in clear English without undue reliance on mathematical formulations, programming nuances, or modeling vernacular.

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Section 2

Potential Uses of the Models

Fundamentally, these models will simulate the natural hydrology and impacts of water management in each of South Carolina's major river basins (See **Section 3**). Modeling will represent the impacts of water withdrawals, return flows, and storage on the water quantity throughout each basin. More specifically, as outlined in the project solicitation, the intended uses of the models are:

1. Evaluate surface-water availability in support of the new Surface Water Withdrawal, Permitting, Use, and Reporting Act;
2. Predict future surface-water availability using projected demands;
3. Develop regional water-supply plans;
4. Test the effectiveness of new water-management strategies or new operating rules; and
5. Evaluate the impacts of future withdrawals on instream flow needs and minimum instream flows as defined by regulation.

DNR and DHEC offered additional insight into envisioned future functionality of the models:

6. Compare managed flows to natural flows when evaluating rivers.
7. Perform "Current Situation Analysis" for quasi-real time operational support: This action would be a probabilistic analysis of current conditions at any future point in time and how conditions are likely to change within 6 or 12 months based on projected use and management patterns. *Application of model functions to facilitate this will depend on the evolution of DNR's and DHEC's envisioned needs, but currently it is envisioned that such a feature could help with real-time drought management and with the formulation of reservoir triggers during regional planning.* This is a model enhancement that would require additional programming in the SWAM platform, but CDM Smith has successfully developed this feature in other models using the same software. CDM Smith will discuss the expected level of effort with DNR and DHEC, so that decisions can be made about prioritizing and implementing this and the other possible future enhancements described herein.
8. Using near-term hydrologic flow forecasts (for example, 60-day streamflow forecasts from NOAA) for month-to-month operational planning. This could be accomplished in the current SWAM platform by substituting historical hydrologic timeseries with flow forecasts. However, it may be useful to develop processing tools (inside or outside of SWAM) to facilitate or partially automate this process.
9. Update Unimpaired Flows (UIFs) on a regular basis: It is envisioned that UIF datasets may need to be periodically revised with future information, or revised at the occurrence of a new drought of record. The Project Team is currently evaluating alternative tools for computing the UIFs, one of which includes the SWAM model itself. Regardless of what tool is used, they will be made available to DNR and DHEC so that future adjustments can be made based on new data collected, and the resulting UIFs can be ported back into the SWAM models.

To these ends, the models will have appropriate resolution in the following areas (see also **Section 7**):

- **Geographic Space**: For example, river networks will include tributaries that are deemed to have current or potential value for water supply and that can be supported by local or regional flow data. Likewise, guidelines will be established for the inclusion of lakes and reservoirs based on usage, size, and other factors. .
- **Time:** The models will include historical data covering a broad range of hydrologic conditions, extending back in time as far as possible, so that probabilities of occurrence of any particular condition can be reasonably approximated in addressing future conditions. Also, the model time step, or the increment of time in which each full set of flow and water management calculations will be performed, will be variable such that the daily constraints and/or impacts of water management regulations and strategies can be evaluated, or so that planning can take place on a broader, monthly basis.

Section 3

River Basin Delineation

South Carolina has delineated eight major river basins, as illustrated in **Figure 3-1**. A surface water model will be developed for each basin (eight separate models). The Savannah River Basin is shared with Georgia, and information from Georgia's statewide planning and modeling efforts will be used to support the South Carolina Savannah River Model. Likewise, the Broad, Catawba, and Pee Dee Rivers all originate in North Carolina, and information will be obtained from modeling efforts in North Carolina (and potentially USGS gages) to provide boundary flows for the South Carolina models at the state line.

Figure 3-1
South Carolina River Basin Delineation

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Section 4

Overview of the SWAM Modeling Tool

The Simplified Water Allocation Model (SWAM) will be used to simulate the surface water hydrology and water management operations for the eight South Carolina basins. The model was developed as a simple, yet thorough, means for water managers to better understand the availability of water in large basins, as well as the impacts of regulatory constraints and operational needs. The model is housed within familiar spreadsheet software (MS Excel), but it is driven by computational code written in Visual Basic for Applications (VBA). The advantages of such a model include its universal familiarity, the ability to manipulate and customize output, flexibility in resolution and operating rules, and ease of adaptation with additional programming.

4.1 Intended Functionality and Past Usage

SWAM was developed by CDM Smith to address an identified need for a networked generalized water allocation modeling tool that could be easily and simply applied for planning by a wide range of end-users. SWAM is designed to be intuitive in its use and streamlined in functionality and data requirements, while still maintaining the key elements of water allocation modeling. SWAM was designed to provide efficient planning-level analyses of water supply systems and river basins.

Like most water allocation models, SWAM calculates physically and legally available water, diversions, storage and release, consumption, and return flows at user-defined nodes in a networked river system. Municipal, industrial (including thermoelectric power), and agricultural demands can be specified and/or calculated in the model. Legal availability of water is calculated based on prioritized permitted withdrawals, downstream demands and physical availability (after downstream withdrawals or uses with higher priorities are accounted for), and anticipated return flows. Additional features in SWAM include easily-parameterized municipal and industrial (M&I) conservation and reuse programs, agricultural- land transfers, groundwater pumping, and interbasin transfers. Multiple layers of complexity are available as options in SWAM to allow for easy development of a range of systems, from the very simple to the more complex. For example, SWAM's reservoir object can include only basic hydrology-dependent calculations (storage as a function of inflow, outflow, and evaporation) or can include operational rules of varying complexity, prescribed monthly releases, a set of prioritized monthly releases, or a set of conditional release rules (dependent on hydrology). The user can choose the appropriate level of complexity given the modeling objectives and data availability.

SWAM currently operates on a monthly time step. However, for application in South Carolina, the software is being enhanced to allow for daily time step simulations. Additionally, the current version of the model is constrained to a total of up to eighty (80) M&I water user and eighty (80) agricultural water user nodes. This constraint can also be easily relieved, if necessary, for this project.

SWAM has been used previously to support water supply planning studies in Colorado (State Water Plan, Arkansas River basin implementation plan), Oklahoma (State climate change impacts on reservoir yield), and Texas (City of Wichita Falls reuse water analysis).

4.2 User's Manual Overview

SWAM is documented in a User's Manual which will be available to all authorized users of the models developed for this study. **Figure 4-1** shows the Table of Contents. The manual explains the object-oriented environment and how to navigate and construct models; the objects available within the tool; and the ways in which demand, operations, flows, and storage levels are computed.

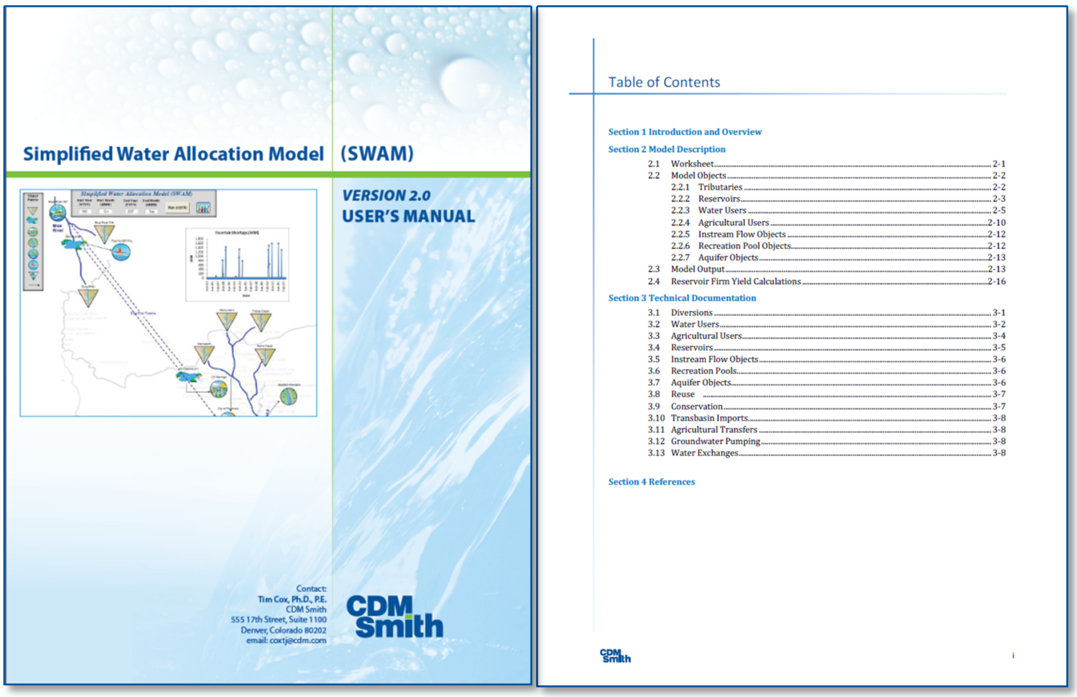

Figure 4-1
SWAM User's Manual: Table of Contents

4.3 Basic Modeling Structure

Each of the eight major river basins described in Section 3 will be modeled as separate models. Each basin model will consist of a network of tributary inflows, simulation reaches, reservoirs, water user nodes, and instream flow targets (if applicable). SWAM allocates water across all basin nodes according to node demands, physical availability, legal availability (permit allowance), infrastructure constraints (storage, diversion capacity), and relative priority of use (if applicable). Relative priorities are assigned to each water- user node in the basin. During times of water shortage, the model optimizes the allocation of water to satisfy user demands in strict order of priority, which may include demands and instream flow requirements (see Section 8.4 for a discussion of how SWAM can simulate riparian water rights in South Carolina: SWAM satisfies demand nodes one by one, in a user-established sequence of priorities which may be as simple as upstream to downstream, or more complex, such as instream flow prioritized above upstream withdrawals.). As part of this allocation, the model considers both upstream and downstream demands and relative priorities when allocating water at a given node. In this way, water user demands (or instream flow targets) with the highest priorities will be fully satisfied prior to allocating water to lower priority users (who may experience shortages during dry periods).

Tributary flows provide the fundamental hydrologic seed for model water allocation simulations. SWAM does not perform rainfall-runoff calculations but rather routes and allocates prescribed flows, generally defined at the top of simulation reaches (tributary inflows). Flow data, rather than precipitation data, are therefore critical to the construction of accurate models. Development of flow inputs is described further in Sections 5 and 6. Tributary inflows are routed downstream by combining flows at confluence locations, subtracting flows at diversion points, and adding flows at return flow locations. Additionally, reach gains or losses (per unit stream length) can be included in the model, as defined by the model user. Lastly, time lags associated with return flows, particularly those that might be delivered back to the stream via groundwater, can be defined by the user for incorporation into the overall flow routing performed by the model.

In some cases, basin reaches will not need to be explicitly included in the models but can be simply represented as point inflows to a higher order reach (implicit reaches). Implicit reaches will include those tributaries in the basins that have no significant operations or withdrawals, current or anticipated. Gaged or estimated flows at the downstream end of the tributary (i.e. at the confluence) will be prescribed for implicit reaches in the models. Differences between explicit and implicit reaches are further described in **Section 8**.

SWAM reservoir objects can be defined as either on-channel (online) or off-channel (offline) and are characterized according to reservoir bathymetry, evaporation rates, individual water user accounts, and operational rules. All major reservoirs in the river basins will be included in the models. Operations will be simulated at varying levels of complexity, as needed, for modeling objectives and as constrained by SWAM functionality. Model reservoir operations options are described below.

Water-user nodes will include both M&I users and agricultural users, represented with separate object types in the model. M&I user nodes will likely include municipal water providers (cities and towns), golf courses, the energy sector, and large industrial users. Each water user, at the most basic level, will be characterized in the model according to monthly variable water demands (disaggregated according to daily usage patterns), a portfolio of supply sources, water permits, storage accounts in local reservoirs, and return flow details. It should be noted that return flows are not represented in SWAM as separate data objects. Rather they are included as components of the water user objects, characterized according to consumptive vs. non-consumptive usage patterns, downstream return locations, and time lags (if applicable). Time lags are likely to only be significant for returns delivered via groundwater flow.

Environmental flow targets or requirements also can be specified in SWAM using the “instream flow” object. Environmental flows can be specified in the model as a constant annual or monthly variable value. Priorities associated with the environmental flows can be easily manipulated in the model. These model objects will likely be important components of State “what if” planning and permitting simulations.

4.4 Options for Operating Rules

Up to five different, prioritized, operating rules can be specified in SWAM, that are used to calculate reservoir releases at each time step. These rules can be either absolute (prescribed constant or seasonal target) or conditional, based on hydrologic conditions in the basin. Either type of rule requires a specified release (flow) or storage target that can vary by month with user input, or daily based on daily conditions computed by the model. Conditional rules can be dependent on daily or monthly flow or storage conditions at any location in the modeled network. Reservoir operations can also be governed by a prioritized minimum environmental or recreational pool, or multiple pools, represented in the model with the “rec pool” object.

4.5 Enhancements for South Carolina River Basins

Several enhancements will be added to the SWAM model to meet the technical requirements of the South Carolina surface water models. These features have not been needed in the past, but the enhancements will be incorporated into the VBA code as part of each of the eight models.

- **Daily Time Step**: Many questions about water availability can be answered with a monthly time step in numerical models. Monthly time steps are the default, and predominant, calculation step used in most water allocation models in use today (e.g. State of Colorado, Texas, and California). However, many of the river basins in South Carolina include large hydroelectric generating facilities, and the operations may affect (and can be affected by) daily fluctuations in streamflow. Similarly, future regulations on instream flow requirements may necessitate analysis on a daily timescale in order to more accurately estimate the frequency at which competing water needs can be satisfied. In these cases, it will be important to distinguish three days of inadequate flow from an entire month of inadequate flow. Unimpaired Flows (See **Section 6**) will be stored in the model in both daily and monthly input series.

- **Graphical Icon for USGS Stream Gages:** Since unimpaired flows will be estimated for each USGS gage in the basins (see **Section 6**), a graphical icon will be added to the modeling palette (similar to reservoirs, water uses, etc.) so that model users can easily navigate in the model and locate computed output and comparative timeseries for flow throughout the river network. The primary purpose of the icons will be for visual orientation and data access. Since flow in mainstem channels (for example) will be computed by the model as the accumulation of upstream unimpaired flows and all simulated upstream operations and storage impacts, CDM Smith will work with DNR and DHEC to determine how best to use these objects in the model; whether for comparing impaired to unimpaired flows directly or for other informational purposes.

- **Update Unimpaired Flows (UIFs) on a regular basis**: It is envisioned that UIF datasets may need to be periodically revised with future information, or revised at the occurrence of a new drought of record. The Project Team is currently evaluating alternative tools for computing the UIFs, one of which includes the SWAM model itself. Regardless of what tool is used, they will be made available to DNR and DHEC so that future adjustments can be made based on new data collected, and the resulting UIFs can be ported back into the SWAM models.

Other enhancements not explicitly required in the scope of work have been discussed with DNR and DHEC. The Project Team will work with DNR and DHEC to prioritize these needs and discuss methods of implementation. These enhancements include:

- **Probabilistic “Situation Assessment”:** Though not explicitly required in the scope of work, interest has been expressed in the ability of the model to evaluate operations in “real time”, as conditions in the future unfold. Referred to here as “Situation Assessment,” this feature would allow users to input current conditions (reservoir storage, time of year, etc.) and then simulate up to 12 months into the future using one historical year of hydrology at a time. At the end of each year, the current storage conditions would be reset and the next year would be simulated. The result would be a probabilistic distribution of flow and storage over the upcoming near-

CDM Smith

term period. It is currently envisioned that such a feature could help with real-time drought management and with the formulation of reservoir triggers during regional planning. This is a model enhancement that would require additional programming in the SWAM platform, but CDM Smith has successfully developed this feature in other models using the same software. CDM Smith will discuss expected level of effort with DNR and DHEC, and decisions can be made about prioritizing and implementing future enhancements.

- **Near Term Hydrologic Forecasts:** Interest has been expressed in using near-term hydrologic flow forecasts (for example, 60-day streamflow forecasts from NOAA) for month-to-month operational planning. This could be accomplished in the current SWAM platform by substituting historical hydrologic timeseries with flow forecasts. However, it may be useful to develop processing tools (inside or outside of SWAM) to facilitate or partially automate this process. CDM Smith will discuss expected level of effort with DNR and DHEC, and decisions can be made about prioritizing and implementing future enhancements.

- **Use of HEC DSSVue for Results Analysis:** Interest has been expressed in porting the large datasets of SWAM results into the HEC DSS database format for evaluation and display. CDM Smith will investigate the level of effort needed to facilitate this, and also work with DNR and DHEC to determine the need for improved efficiency in results displays once the models are completed and are being used.

- **The addition of a separate model object (graphical icon) to represent point source discharges:** For point source discharges that are modeled as input time series of flow, a separate model object will be added. Currently, this is done with the Tributary object; however, to prevent user confusion, a separate Point Source icon will be added. *Note: this enhancement is being implemented for the pilot basin.*

- **The addition of model objects (graphical icons) to better represent the various types of registered and permitted water users**: SWAM currently includes Municipal/Industrial (M&I) and Agricultural model objects to represent water users and their withdrawals. The M&I object covers withdrawals from all non-agricultural users including water suppliers, industry, mining operations, golf courses, and energy producers (hydroelectric, and thermoelectric). DHEC and DNR have expressed the desire to have separate water user objects to better represent the registered and permitted water user types. This will be done by adding additional model objects. The functionality of the model objects will be identical to the M&I object; however, the drop-down list accessed by clicking on each object will only show users in the same category as the object. *Note: this enhancement is being implemented for the pilot basin.*

- **The ability to select from a list of standard units for flow and volume.** SWAM currently reports flow in acre-feet per month and volume in acre feet, but is being modified to allow the user to select one of the following groups of units:

    - Cubic feet per second (CFS) for streamflow; million gallons (MG) for storage; million gallons per day (MGD) for withdrawals.

    - Acre feet per month or day (AFM or AFD) for streamflow and withdrawals; acre feet (AF) for volume.

    - Cubic meters per second (CMS) for streamflow and withdrawals; cubic meters (CM) for storage.

4.6 Examples of SWAM Output

SWAM is equipped to provide various forms of standardized output, but the ouput is also easily customizable by users based on their specific needs because the program is housed within the familiar MS Excel platform. Some examples of standard output are included below, in **Figures 4-2** through **4-8**. They are intended to be generic and any numerical values are for reference only – references to specific water bodies are for example only, and do not reflect actual results of analysis. As shown in **Figure 4-8**, SWAM output may be displayed directly in MS Excel for intuitive viewing and evaluation, or written to text files for storage or to possibly facilitate interactions with other programs.

	Priority Rank	Reach (mi)	Location	Water Right (AFM)	Ditch Capacity (AFM)	Storage Capacity (AF)			
Totals				*1,101,000*	*1,100,000*	*29,041*			
Physically Avail. (AFM)	Legally Avail. (AFM)	Diverted (AFM)	Storage (AF)	GW Pumping (AFM)	Demand (AFM)	Shortage (AFM)	Return Flow (AFM)	Release (AFM)	Evap Losses (AFM)
2,253	28,049	1,600	19,746	0	1,600	0	1,520	0	23
144,136	191,771	11,868	29,041	0	6,400	0	2,470	0	320
33,281	43,117	3,400	25,068	0	3,333	0	1,948	0	167
21,430	32,025	3,200	22,552	0	3,200	0	2,320	0	155
19,636	35,619	1,600	22,503	0	1,600	0	1,520	0	50
20,718	36,007	1,600	22,453	0	1,600	0	1,520	0	49
23,400	34,786	1,600	22,405	0	1,600	0	1,520	0	49
14,961	34,957	2,286	23,043	0	1,600	0	1,520	0	48
11,972	36,181	2,386	23,774	0	1,600	0	1,520	0	54
19,622	33,936	2,400	23,713	0	2,400	0	1,844	0	189
44,179	42,506	4,000	23,652	0	4,000	0	2,240	0	226
83,598	94,096	5,200	23,591	0	5,200	0	2,249	0	254
68,225	68,999	6,400	23,531	0	6,400	0	2,240	0	266
46,651	54,952	6,000	23,472	0	6,000	0	2,415	0	235
34,654	50,489	4,800	23,413	0	4,800	0	2,470	0	199
28,266	41,855	3,200	23,355	0	3,200	0	2,320	0	163
19,620	35,268	1,600	23,297	0	1,600	0	1,520	0	58
18,195	33,275	1,600	23,241	0	1,600	0	1,520	0	57
19,975	31,615	1,600	23,184	0	1,600	0	1,520	0	56
19,672	30,724	1,600	23,128	0	1,600	0	1,520	0	56
15,474	32,310	2,231	23,704	0	1,600	0	1,520	0	55
18,772	34,681	2,400	23,643	0	2,400	0	1,844	0	189
31,728	42,524	4,000	23,582	0	4,000	0	2,240	0	225
81,672	157,057	10,718	29,041	0	5,200	0	2,249	0	253
73,094	88,001	6,400	28,927	0	6,400	0	2,240	0	320
58,133	60,232	6,000	28,813	0	6,000	0	2,415	0	289
37,263	37,201	4,800	28,701	0	4,800	0	2,470	0	252
25,603	31,406	3,200	28,590	0	3,200	0	2,320	0	216
15,951	31,601	1,600	28,480	0	1,600	0	1,520	0	110
17,901	33,044	1,600	28,372	0	1,600	0	1,520	0	109
12,249	32,365	2,377	29,041	0	1,600	0	1,520	0	108
2,302	31,151	1,714	29,041	0	1,600	0	1,520	0	114
4,016	34,287	1,714	29,041	0	1,600	0	1,520	0	114
21,029	38,982	2,400	28,927	0	2,400	0	1,844	0	242
78,414	100,342	4,228	29,041	0	4,000	0	2,240	0	278

Figure 4-2
Standard SWAM Summary Tables Output in MS Excel

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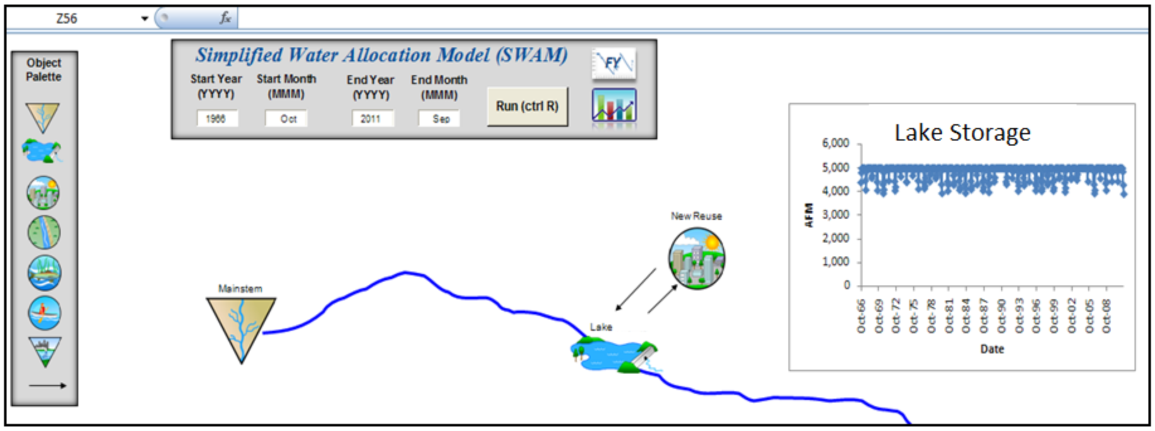

Figure 4-3
Example Output Graph for Reservoir Levels Directly on the Interface Screen

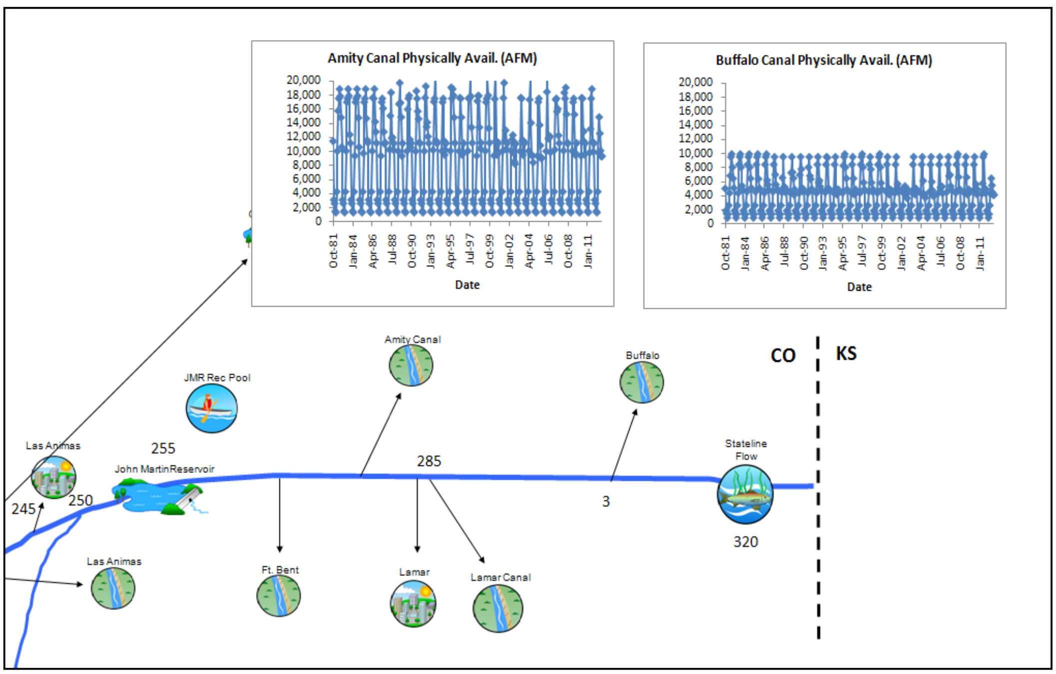

Figure 4-4
Example Output Graphs for Water Availability Directly on the Interface Screen

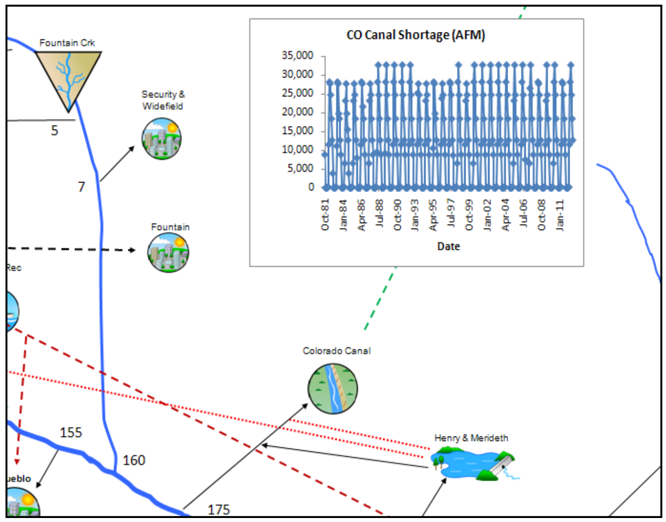

Figure 4-5
Example Output Graph for Water Shortage Directly on the Interface Screen

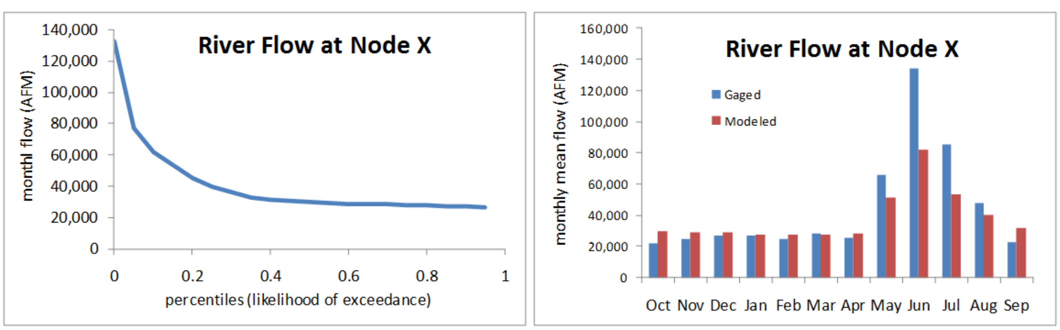

Figure 4-6
Example of Some Statistical Output Summaries Available in SWAM

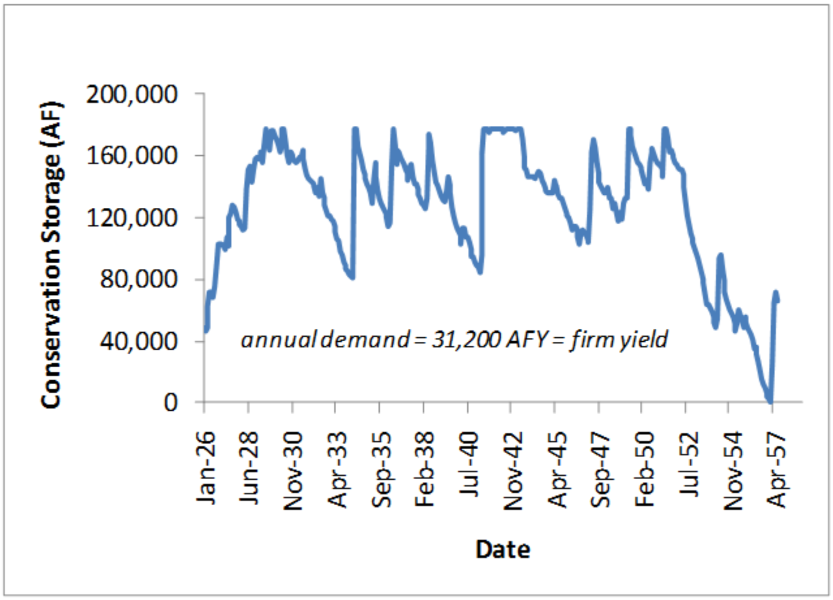

Figure 4-7
Example Output of Reservoir Firm Yield Calculator Function in SWAM

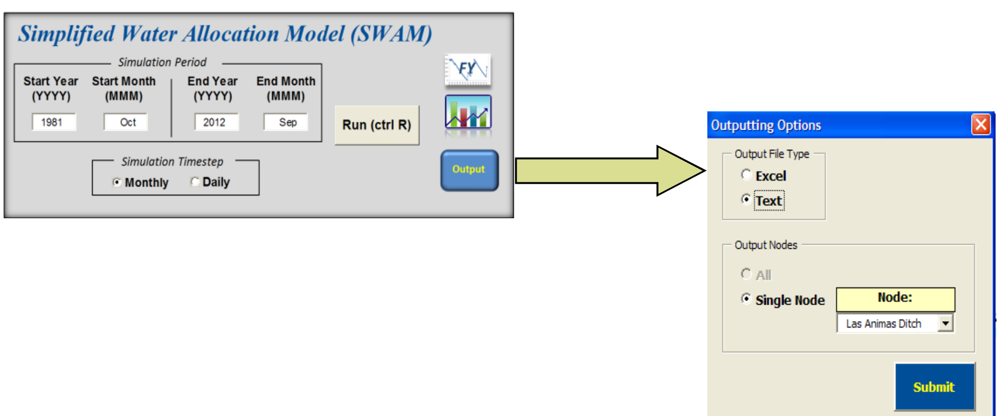

Figure 4-8
Option to Output Data to Spreadsheet or Text File

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Section 5

Modeling Data Requirements

Table 5-1 lists the expected data needs for the surface water models. Some of the data in this list are needed both as model input and for the formulation of Unimpaired Flows (UIFs), which are discussed in more detail in **Section 6.** Generally, data needed for unimpaired flows include historic alterations of river flow, whereas most data to be used as model input generally focus on current or permitted conditions.

Table 5-1: Data Needs for Model Input

Data Category	Data	Use(s)	Potential Sources	Comments
Hydrology	USGS Streamgage Records	Direct model input and/or comparison against model calculated flows as part of calibration process	USGS	Also needed for UIF development, but should be stored in the model for comparative purposes
	Unimpaired Flow Estimates, SC	Direct model input and basis for comparison against managed flows	CDM Smith	Refer to **Section 6** for discussion of methodology and data needs
	Unimpaired Flow Estimates, NC		NC	For the Broad, Catawba, and Pee Dee Basins (it is assumed that USGS gage records near the state line will adequately capture current managed flow conditions from North Carolina).
	Managed Flow Estimates (Current Conditions), NC	Direct model input for scenarios that account for water management outside of SC	NC and USGS	
	Unimpaired Flow Estimates, GA	Direct model input and basis for comparison against managed flows	GA EPD	For the Savannah River Basin
	Managed Flow Estimates (Current Conditions), GA	Direct model input for scenarios that account for water management outside of SC	GA EPD and USGS	
Climate	Historic Precipitation (Daily)	Model input for reservoir surface fluxes	USHCN	~30 sites report to USHCN
	Historic Pan Evaporation (Monthly)		DNR Website	13 sites with data from 1948
	Historic Air Temperature (Daily or Monthly)	Possible need to extend evaporation records using temperature as independent variable.	NCDC, State Climatologist	
Water Use	Current Permitted or Registered Surface Water Withdrawals > 100,000 gpd	Model input for simulating current and future use scenarios	DHEC Database	Includes municipalities, utility districts, thermoelectric power plants, agricultural uses, golf courses, etc.
	Current Permitted Discharges		DHEC Database	Includes municipalities, utility districts, industries, power plants, etc. Would also include any information on controlled discharges (temporarily stored during low flow).

Data Category	Data	Use(s)	Potential Sources	Comments
Water Use (continued)	Population on Septic	Estimate return flows for areas not serviced by public sewers	Water Utilities, DHEC	By area Note that this is probably a very small percentage of the water balance in each basin, and it may be deemed negligible.
	Historic M&I Water Withdrawals	UIF Development, Model Calibration and Validation	DHEC databases; USDA, SCDA, and SC Farm Bureau records; and anecdotal information from registered users/ permittees and dam operators	This will largely overlap with UIF data collection and development, but will be useful in confirming the models' ability to recreate historic flows as measured by USGS stream gages.
	Historic Ag Water Withdrawawls			
	Historic Industrial / Energy Water Withdrawals			
	Historic Discharges			
	Historic Reservoir Operations and Levels			
	Population	UIF Development	US Census	May be used to estimate historical withdrawals, when no data or only anecdotal information is available
Storage	Reservoir Storage-Area-Elevation Curves	Track reservoir storage and elevation, and compute area for direct rainfall and evaporation.	Dam operators, FERC Licenses, USACE	See **Section 7** for guidelines on what reservoirs to include explicitly
	Reservoir Operating Rules	Allow reservoirs to react to the full range of plausible hydrologic and demand conditions		Includes FERC licenses for hydroelectric dams
	Spillway Rating Curves	Estimate plausible rates of outflow, especially for daily analysis.		
Geography	Land use percentages	Help estimate return flows, assist in determination of tributary potential	DNR, USC	Undeveloped, residential, commercial, agricultural, etc. (generally high level aggregate categories)
	Spatially distributed acreage of crop types	Estimate agricultural water demand and return flows	USDA, SCDA, and SC Farm Bureau	
Regulations	Interbasin Transfer Permits	Current and future use scenarios and possible adjustment of measured flow for UIF development	DNR/DHEC	
	Instream Flow Requirements		DNR/DHEC	
	Drought Management Plans and Requirements	Adjust recent operations for UIFs, and adjust operations for future use scenarios	State Climatology Website	
	Contingency Plan Requirements		DHEC	Future use permits may require identification of contingent water sources

CDM Smith

Section 6

Unimpaired Flow Development

Unimpaired Flows (UIFs) are defined as the flow in a river in a completely unaltered state. In other words, UIFs are the natural hydrologic flows in a river, unmodified by human impacts such as water withdrawals and discharges (which affect the volume of flow), and temporary storage (which affects both the volume and timing of flow). UIFs serve two purposes in a water quantity model:

- Provide baseline input to models so that future management activity can be evaluated on a realistic basis of naturally-occurring water; and
- Provide a baseline for evaluating impacts of human use by allowing analysts to compare altered flows to unimpaired flows.

A separate procedural plan for the development of UIFs in each basin will be written and distributed separately from this overarching modeling plan. The procedural plans will discuss the data needs, procedures, resolution, decision making protocols, etc. needed to consistently estimate UIFs throughout each of the eight basins. The general procedure is outlined in **Figure 6-1**.

Generally, UIFs are calculated as:

> ***Unimpaired Flow*** *= Measured Gage Flow + River Withdrawals +*
> *Reservoir Withdrawals – Reservoir Releases – Wastewater Discharges*
> *– Irrigation Return Flow – Septic/Other Return Flow+ Reservoir Surface Evaporation*
> *– Reservoir Surface Precipitation + Upstream Change in Reservoir Storage*

Additionally, flows will be adjusted after reservoir construction to account for runoff that would have occurred on land that is now submerged and which is not necessarily captured in USGS gage records

UIFs will be computed on a daily basis, using USGS daily flow records.. Gap filling and record extension procedures will be applied as needed for sites that are ungaged or have incomplete records. Much of the available data needed for the computation of UIFs will be available at a monthly timescale, and approximations for daily disaggregation will be employed. Because of this, while the UIFs will have daily resolution, some of the elements comprising the UIFs will only have monthly precision. This type of calculation is common in the development of UIFs for similar modeling studies throughout the United States.

Compared to the data requirements list for model development presented in **Section 5**, the data needed for the development of unimpaired flows will be very specific historic records, as opposed to current conditions and permitted or registered ("possible") water uses. UIFs will be back-calculated by adding and subtracting actual operating records of withdrawals, discharges, and storage dynamics to/from daily USGS streamflow gages. It may be that the SWAM modeling platform is the most effective tool for this process, but it can also be accomplished in spreadsheet files or databases.

UIFs will be computed for every USGS gage in the basin that is deemed to represent altered flow. Rather than compute UIFs for individual additive reaches from upstream to downstream (a process by which error can accumulate), CDM Smith will compute UIFs for the entire upstream area of each gage, and subtract upstream UIFs to determine incremental UIFs between gages. This avoids accumulation of error or uncertainty by adding calculated UIFs together into a network.

UIFs for basins that originate in North Carolina (Broad, Catawba, and Pee Dee) have already been developed, or will be developed as part of ongoing surface water modeling studies in North Carolina. CDM Smith will obtain these calculations as boundary condition inputs for the relevant South Carolina models. However, while this will provide a basis for comparing managed flows to natural flows, it may be more practical for future planning to also include managed flows from North Carolina as optional model boundary conditions. The reason is because flows entering South Carolina are based on operating practices regulated by North Carolina, and/or by interstate agreements, neither of which can be controlled by South Carolina. It is recommended that the managed flows from North Carolina be established as the default boundary conditions.

Similarly, for the Savannah River Basin which is shared with Georgia, UIFs have already been developed for the entire basin as part of statewide planning work in Georgia. CDM Smith will obtain the UIFs for both the Georgia and South Carolina portions of the basin as model input (Georgia is currently updating these to 2013). Additionally, CDM Smith will include managed flows from the Georgia tributaries for the same reasons that the calculations will include managed flows from North Carolina. South Carolina may not have influence over these flows, and for future planning, it will be important to combine natural flows in South Carolina with managed flows originating in Georgia.

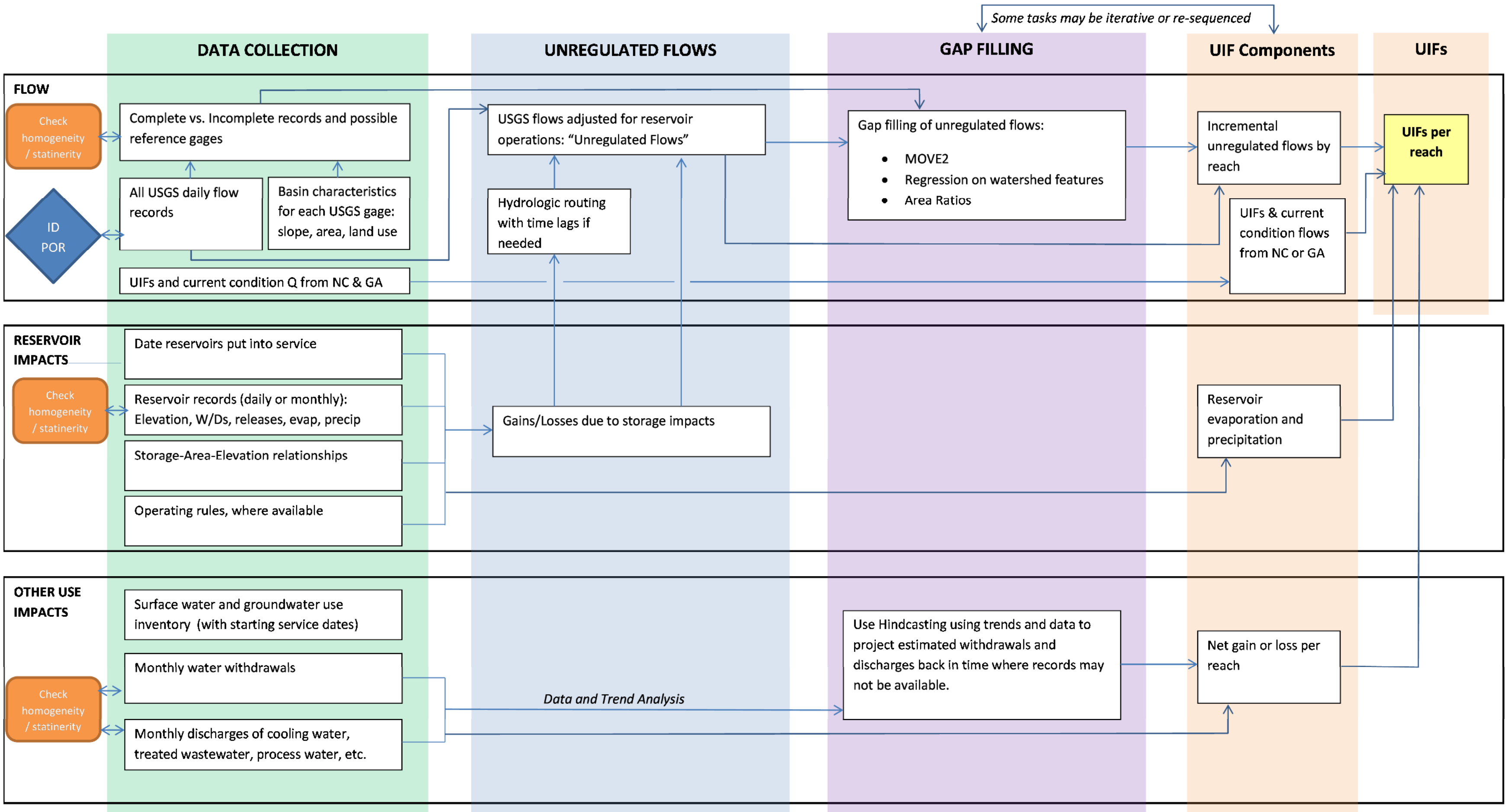

Figure 6-1
Unimpaired Flow Methodology

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Section 7

Model Resolution

7.1 Spatial Scale

The models will be discretized into reaches along the mainstem and higher-order tributaries. Reach lengths will be determined so that major changes in flow, such as tributary confluences, point source discharges, and withdrawal locations, may be isolated as much as possible as the only major impact to a reach. Inclusion of specific features of the river network, such as high- order tributaries, reservoirs, and water uses, will require some judgment regarding their impacts. Guidelines are offered below, but are not necessarily fixed rules for explicit or implicit inclusion of such features. Certain cases that fall outside the bounds of these guidelines may still be deemed negligible or relevant for other reasons, and CDM Smith will consult with DNR and DHEC in such cases. CDM Smith will also summarize all features that are simulated explicitly, and those which are included implicitly due to their relative impacts on the river systems.

Many tributaries will be modeled explicitly.. Others will be included implicitly as part of the aggregate change in flow within a larger reach. The following guidelines will be used to determine if a tributary will be modeled explicitly:

- If a tributary currently supports permitted withdrawals, it will be included explicitly.
- If a tributary could support at least one continuous withdrawal of 100,000 gpd while satisfying South Carolina's new instream flow provisions through even the most severe drought of record, it will be included explicitly.
- If a tributary cannot currently support a withdrawal of 100,000 gpd while satisfying South Carolina's new instream flow provisions, but is in a potential area of economic development, it will be included explicitly if external hydrologic analysis suggests that an increase in impervious area could dramatically increase runoff potential. In such cases, boundary conditions flows may need to be adjusted in the model for special scenarios.

If DNR and/or DHEC believe that a tributary that does not satisfy the criteria above is worthy of explicit inclusion for other reasons, (for example, regulatory scrutiny or histories of flow concerns), such tributaries will be included in the model, within reason, and based on collaborative discussions between DNR, DHEC, and CDM Smith.

Similarly, reservoirs will be included explicitly in the model if any of the following conditions are met:

- The reservoir produces hydroelectric power according to prescribed operating rules, or is governed in any way by a Federal Energy Regulatory Commission (FERC) license.
- The reservoir supports permitted or registered withdrawals from the mainstem or high-order tributaries. (Reservoir dynamics from lower-order tributaries may not be included if their impacts can be aggregated into lumped withdrawals, and storage impacts are deemed negligible).

- The reservoir is located on a direct tributary to the main stem that is already being simulated based on described guidelines.

Similarly, water use nodes will be represented as follows:

- Any registered or permitted water withdrawal greater than 100,000 gpd (Municipal, Industrial, Agricultural) will be simulated explicitly.
- Discharges of water or wastewater permitted according to the National Pollution Discharge Elimination System (NPDES) can be simulated explicitly as an inflow to the stream network, or implicitly as return flows from M&I users. The distinction will likely depend on the size of the discharge relative to average stream flow conditions.
- Any documented or estimated withdrawals that are smaller than 100,000 gpd (golf courses, irrigation, for example) will be included implicitly in aggregated reach losses, or lumped together into aggregated total ‘small’ withdrawals within a reach and removed explicitly from one node.

7.2 Time Scales

The models can be run on either daily or monthly time steps at the user’s discretion. Monthly time steps are expected to be useful for comparing alternative basin management strategies and overarching policies. Daily time steps are expected to be useful when evaluating the impacts and utilization of hydroelectric power plants, and when evaluating the efficacy of current and future use patterns with respect to instream flow regulations, recommendations, and water availability.The historic period of record embedded in the model input (UIFs) will extend back in history as far as the furthest continuous USGS streamflow gage records. Other records will be extended to match this earliest date. Although much of the flow input to the model will be synthetic, the value of a lengthy record, even if approximate, is that DNR, DHEC, and other users can evaluate results over a large range of hydrologic and climate conditions. In other words, the long hydrologic record will provide a measure of the historic frequency (or likelihood) of certain flow conditions, and such understanding is often at the root of many permitting decisions.

As previously stated, some of the historic information that will be used to create UIFs will be available only at monthly resolution. These data sets will be disaggregated into estimated daily distributions (to be documented in the forthcoming memorandum on UIF methodology). This practice is standard and is important because model users will need to be aware that, while the models have daily resolution for analysis, the precision of the input data will not always be daily.

Section 8

Model Setup

8.1 General Approach and Flow Chart

Guided by the targeted spatial and temporal scales discussed above, models will be constructed for each of the eight major river basins using the SWAM software. Hydrologic inputs to the model will be in the form of monthly and daily flow timeseries data prescribed for multiple model tributary objects (Objects are visual icons that store relevant data, and are available for tributaries, reservoirs, water uses, etc.).In some cases, these tributary objects will be part of an *explicit* representation of a model reach. Explicit tributaries are those that include any number of water user nodes and/or reservoir objects. For explicit tributaries, the model calculates physically and legally available flow at each constructed node and allocates water accordingly. For these types of tributary objects, flow inputs are generally defined as headwater flows – occurring at the top of the modeled reach.

In other cases, some tributary objects will merely serve as point inflows to a larger explicitly simulated reach (to represent smaller, incremental flow inputs) and are referred to here as "implicit tributaries". Implicit tributaries generally either don't serve as direct sources of supply for any major water users (no nodes) or they include incremental flow that is significant but does not require direct simulation (e.g. will remain unchanged for future "what if" model scenarios). Flows from these tributaries, delivered to downstream reaches, are important, however, to the overall basin water balance and thus are included as point sources in the models. As discussed in Section 7, decisions about which tributaries are modeled explicitly to evaluate and which are considered to be implicit inputs will be made collaboratively with DNR, DHEC, and CDM Smith. For implicit tributaries, downstream flow records should serve as the primary input. These downstream records are generally derived from flow gages near the tributary mouth and should be reflective of current upstream operations. For ungaged sub-basins, flow estimation techniques will be used to provide initial estimates of point flows in the model. These initial estimates may be adjusted during the model calibration process, described below.

Water user objects, either agricultural or M&I, will be added to each model to represent each major water user in the basin based on agreed-upon size criteria (see **Section 7**). For small water users falling below the designated threshold for discrete representation, some form of aggregation will likely be applied. In other words, aggregate water user objects will be created to represent the aggregate sum of small water users within a given region or sub-basin. Key inputs for water- user objects include: monthly water demands, withdrawal permit details, infrastructure constraints, storage availability, relative diversion and return flow locations, supply portfolio information (including direct surface, surface storage, and groundwater pumping), and (if applicable) relative priorities of withdrawal. The withdrawal priorities are only important in the model during simulations of water shortfalls. Water user demand inputs are described further below.

Reservoir objects in SWAM serve as the physical representation of basin reservoirs and can be on or off-channel, relative to the river system. Each reservoir object is generally linked to one or more water -user objects via user storage "accounts". Any number of water-user accounts can reside within a given reservoir object. Reservoir objects are represented according to capacity and bathymetry data, surface evaporation rates, and operational "rules" that drive the calculation of reservoir water releases. All major reservoirs in a given river basin will be explicitly included in the constructed models as described in **Section 7**.

Once all model objects have been constructed in SWAM, with initial representation, a model validation/calibration exercise will be done. **Section 9** describes the general process of validating the model; and if necessary, calibrating certain unknown variables.

A flow diagram summary of the model construction and validation is shown in **Figure 8-1**.

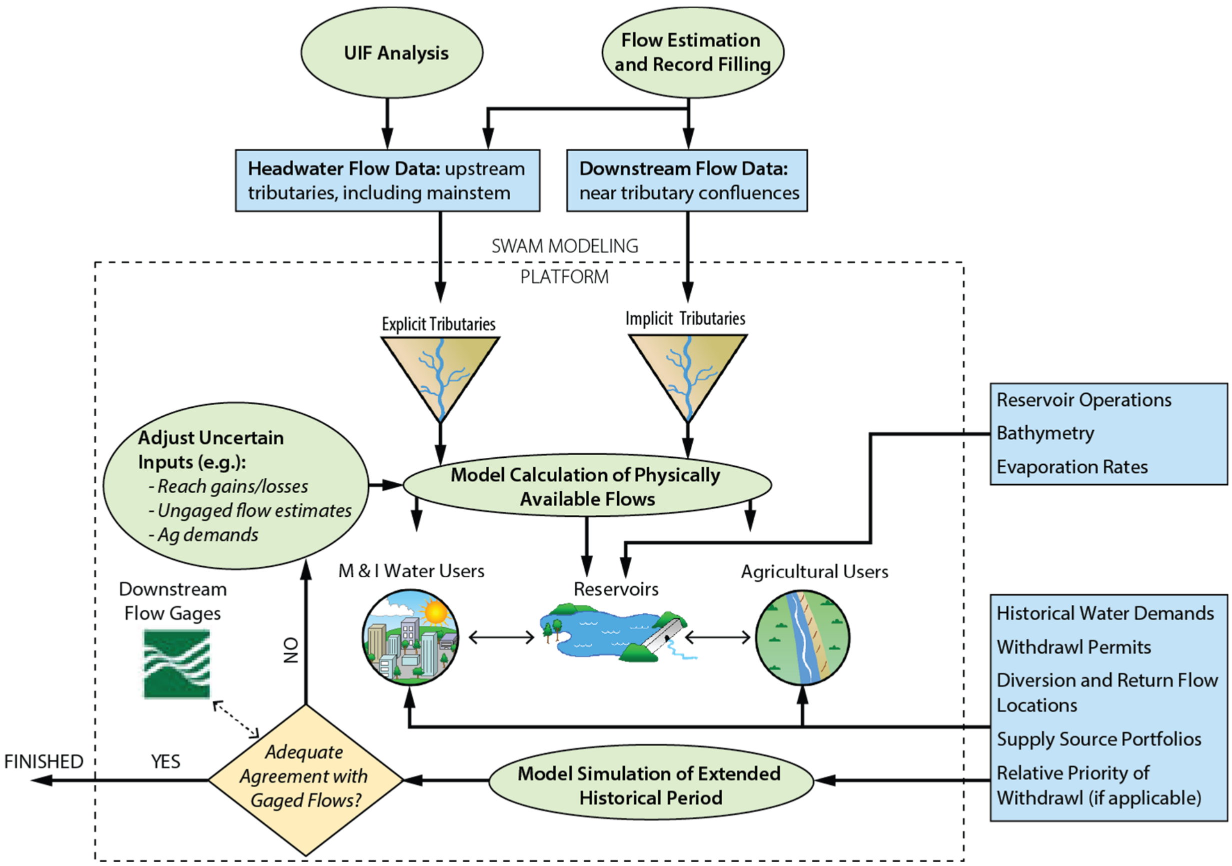

Figure 8-1
SWAM Construction and Validation Process

8.2 Demand Inputs: Municipal, Industrial, and Agricultural

M&I demand will be input as part of individual water user nodes in the constructed models. For future planning simulations existing permit values will likely be used to quantify demands, even if historic withdrawals do not reach allocated withdrawal limits. The use of permit limits for these future planning simulations, rather than reported withdrawals, would be to account for all allowable uses of the water in order to fully characterize water availability and instream impacts. Additionally, new nodes may be added to the model to evaluate future withdrawal applications. However, for any scenario, demand at any node can be adjusted by the user to represent current or historical patterns, current permitted values, or future permit considerations. For model calibration simulations, or other historical hind casting simulations, reported historical water usage will be used to parameterize M&I object demands to best characterize historical basin operations.

Agricultural withdrawals can be accounted for in one of two ways in SWAM, depending on availability of data. If surface water withdrawals are greater than 100,000 gpd, these will be entered just as the M&I demands are entered, as explained above. If withdrawal values are lower, SWAM is equipped with algorithms that can estimate water usage based on acreage and crop type within a basin. Nodes will be added (likely aggregating agricultural usage in a reach) to account for these withdrawals.

As documentation and anecdotal information allow, groundwater and surface water usage for irrigation will be separated. The SWAM models will include both surface and groundwater usage, as deemed significant. However, only surface sources of supply (rivers and reservoirs) will be explicitly tracked in the model water balance. In other words, groundwater usage will be governed only by prescribed pumping rates rather than direct calculations of aquifer storage availability. Return flows from groundwater usage to surface waters, if significant, will be included in the models. As needed, the impact of groundwater withdrawals on surface water flows can be represented as the net impact of groundwater withdrawals and return flows. In the Coastal Plain basins, it is assumed that any groundwater used would generally originate from deep aquifers, and that there would be little interaction with the surface water. It is noted that in South Carolina, aquifers are generally sources of water to streams.

8.3 Discharges and Return Flows

The models will account for permitted discharges as discrete point-source discharges at individual locations, as documented in the NPDES database.

Return flows (generally via groundwater) will be estimated for two types of land areas, if deemed necessary based on expected contribution to the water budget within a basin: Communities dominated by septic systems for wastewater disposal and agricultural areas. Since these flows are generally not governed by permits or otherwise documented, SWAM can estimate these nonpoint flows into the receiving streams in two ways:

- The return flows can be computed or aggregated outside the model (or based on any information otherwise available). These flows can then be input as discrete discharges using the tributary object.
- These return flows can be calculated in the model, at each time step, as a function of water usage characteristics (e.g. indoor versus outdoor use for M&I, crop type and irrigation efficiencies for Ag) and seasonal patterns

Decisions on which approach will be used may vary from basin to basin, and even within a basin, based on the availability of pertinent data.

8.4 Guidelines for Withdrawal Priorities

SWAM is designed to accommodate both principal types of water use permitting in the United States:

- Riparian Rights, where authorization to use water is based on ownership of land abutting the stream and no priorities are established between users,
- Water Rights and Prior Appropriations, where authorization to use water is based on purchased ownership of the water itself, and priority of usage is based on the filing date.

Riparian doctrine is generally applied in the Eastern U.S. (this includes South Carolina). Under riparian practices, permitting must account for all river usage because all users are assumed to be entitled to their allocated uses at all times. Under Prior Appropriation doctrine, generally applied in the Western U.S., rivers are frequently over-allocated, and use priority is established in the order of most senior to most junior water rights.

SWAM handles either doctrine by allowing the user to prioritize each water withdrawal. To represent riparian practices, users generally establish priorities from upstream to downstream, allowing all authorized users access to their water throughout the river network and accounting for all upstream uses at each location. This approach also tests the basin-wide impacts of the cumulative withdrawals and is how the SWAM models for South Carolina will be developed. An exception may exist if, for example, a downstream thermoelectric plant or hydroelectric plant requires, by contract or agreement, a certain amount of water that has a priority of use higher than a nearby municipal withdrawal. Other exceptions may apply (see **Section 8.6**) to represent a required instream flow as a water use that has regulatory precedence over upstream or downstream withdrawals. In these cases, users can easily re-prioritize water uses, such that the highest priorities are always accommodated first. These calculations are made during each time step, and water is allocated to users in full until it is no longer available. The model does not distribute shortages among users, although either method of estimating water shortages is an equally useful way of evaluating the adequacy of supply. For riparian practices, the potential impacts are better measured by allowing full access to water where it is available, and restricting it where it is not. This approach is accomplished in SWAM by prioritizing from upstream to downstream.

8.5 Guidelines for Operating Rule Representation

Reservoir operations will be defined for each reservoir-model object according to the available model-rule set described in **Section 4.2**. Only well-defined rules that are deemed important to the overall reservoir water balance and fitting within model time step constraints will be included. In some cases, important operational considerations may be simplified in the model construct to accommodate available model functionality. In other cases, the model code may require augmentation to accommodate explicit rules that cannot be easily represented with existing functionality. Fundamentally, if an operating rule can affect the flows at a daily level, it will be included in the model, but if it has a negligible effect on daily flow, it will not be required. An example of an operating rule that may not require inclusion would be a 15-minute ramp rate for a turbine, an event that happens on a timescale much finer than even a daily time step, and which does not appreciably affect the daily flows. Conversely, as an example of a rule that would be required is a flow trigger upstream to switch between three turbines and two. This affects the volume of water passed in a day, and therefore has a material impact on the model results at a daily time step. Decisions on the simplification of rules to fit existing model functions, the augmentation of model code to accommodate rules beyond the existing model functions, and the inclusion of rules based on their impact on the daily water balance will be made collaboratively with DNR, DHEC, and CDM Smith. The entity (water withdrawer) responsible for the rule will also be consulted to confirm that the model is accurately representing the operating rule or rules.

Best efforts will be made to fully represent all operations impacting downstream water availability, either past or present. Operations tied to downstream water availability are tied to reservoir releases. Such reservoir releases can be triggered or tiered by:

- Water demand

- Time of year
- Reservoir water levels (locally or elsewhere in the river network)
- Hydrologic flows at other locations in the river

8.6 Guidelines for Applying Streamflow Regulations

South Carolina has recently established minimum streamflow criteria that will be applied to future water-use permits. In SWAM, these criteria can be represented as a water use (instream) that has priority over future withdrawals, but which may not have precedence over historic withdrawal permits if they are grandfathered into the new regulations. CDM Smith will review the relative priorities that any instream flow provision will have in the models over other historic and future uses.

As a corollary to the new minimum flow requirements, new water users may be required to develop and implement contingency plans for water supply when streamflow drops below certain thresholds. These rules will also be programmed into SWAM such that future withdrawals will be conditional on flow conditions in the relevant river reach. If the contingency plans require withdrawals from elsewhere in the basin, these will be simulated to the extent practical based on available data, size of withdrawal, etc.

8.7 Assumptions and Simplifications

Any environmental computer model is a simplification of the natural environment and the processes that occur within it. A key aspect of any modeling project, therefore, is the achievement of consensus on all simplifications and assumptions. Not all of these will be known prior to the development of models, so several will be listed in this document as examples. Distribution and discussion of these lists will help foster a broad understanding of what the models can and cannot do, and how the output should be used and interpreted.

Example Assumptions and Simplifications:

- Return flows from agriculture will be estimated using fractions of water used for irrigation.
- No surface water/groundwater interactions will be accounted for explicitly in these surface water assessment tools unless clear and documented evidence of substantial impacts to surface water flows exists for phenomena which are not captured by either estimated return flows or USGS gage records.
- Low-order tributaries (small headwater streams) may be aggregated into single boundary condition flows for each major tributary so that the represented river network can focus on reaches in which management occurs or could occur.
- Smaller water users (< 100,000 gpd) will be aggregated into single model objects.

Naturally, the assumptions and simplifications for each basin will become more specific as each model is developed.

8.8 Types of Scenarios

The SWAM models can currently be used to run two different types of scenarios (1) Extended Simulations and (2) Forecast Simulations, both with several variants:

- Extended Simulations: These scenarios will be run over the historical period of record, using UIFs as the foundation and overlaying current and future water management practices. Results can be customized based on discussions with DNR/DHEC, or subsequently by model users; but results will generally be cast either as timeseries of flows, uses, water levels, etc, that can be evaluated on their own or compared against UIFs, or as frequencies/probabilities of reaching or exceeding certain thresholds. Generally, this mode of operations can be used to:
  - Evaluate new permits
  - Examine impacts of future demand levels basin-wide
  - Evaluate alternative operating rules
  - Evaluate the efficacy of pending regulations
  - Develop basin-wide management plans

  These scenarios can be run at either a daily or monthly time step. Additionally, users will have the option of selecting UIFs from North Carolina and Georgia as boundary conditions, or to use managed flows from these adjacent states as perhaps more representative of available water for South Carolina to manage within its own borders. Both data sets from North Carolina and Georgia will be stored in the appropriate basin models and will be interchangeable.

- Forecast Simulations: If available from NOAA or other sources, short-term streamflow forecasts (60 – 90 days, for example) can be input to the model for evaluation of real-time management practices.

A possible third type of scenario exists for conducting Probabilistic Simulations. Though not explicitly required in the scope of work, interest has been expressed in the ability of the model to evaluate operations on a regular basis as conditions in the future evolve. Referred to herein as "Situation Assessment," this feature would allow users to input current conditions (reservoir storage, time of year, etc.) and then simulate 6 – 12 months into the future using one historical year of hydrology at a time. At the end of each year, the current storage conditions would be reset and the next year would be simulated. The result would be a probabilistic distribution of flow and storage over the determined period (6 or 12 months, for example). CDM Smith will discuss the potential value of this feature with DNR and DHEC and, collectively, decide if and how to include it.

Section 9

Model Validation

Unlike models that convert rainfall to runoff through a series of parameterized equations, SWAM models will be based on hydrologic records computed from historical measurements. As such, the process of evaluating the performance of these models (their ability to reproduce historical observations) will be more accurately characterized as a “validation” process, in which the computed flows once management measures are superimposed on UIFs are checked against historical records. As discussed below, each basin may include unknown or undocumented phenomena which will be adjusted (“calibrated”) so that simulated flow matches historical flow measurements.

In this exercise, calculated downstream flows and reservoir storage levels for a given historical simulation period will be compared to observed data. A number of performance metrics will be used to assess the model’s ability to reproduce historical hydrology and water usage, including timeseries plots of storage and river flow, annual flow totals (overall water balance), monthly mean-flow values (seasonality), flow and storage percentile plots (range of variability), key statistical low-flow values such as the 7-day and 30-day low flow levels in a given year and/or with a recurrence interval of 10 years, and water user shortfalls (allocation of physical flows). Additional statistical metrics can also be used as needed and applicable, examples of which include the coefficient of determination (R^2), Nash-Sutcliffe Efficiency, and indicators of bias.[1] Judgment will used to determine whether a model is adequately capturing key system dynamics and reproducing historical hydrology and operations to a satisfactory level. If the initial model construct does not achieve satisfactory results, a calibration process will be applied whereby selected model parameters are adjusted until adequate results are achieved. Model calibration parameters will only include those that are not known with certainty and may include: reach gains or losses, ungagged tributary flow estimates, and unreported (estimated) agricultural demands.

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[1] Computation of various statistical measures of model performance are documented in the following reference: *D. N. Moriasi, J. G. Arnold, M. W. Van Liew, R. L. Bingner, R. D. Harmel, T. L. Veith, 2007, Model evaluation guidelines for systematic quantification of accuracy in watershed simulations, American Society of Agricultural and Biological Engineers, Vol. 50(3): 885-900.*

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Section 10

Schedule of River Basins and Model Delivery Procedures

10.1 Schedule

Baseline models of all eight river basins will be completed over a two year period, with all models completed by August, 2016. During the project kick-off meeting, the basins were tentatively prioritized to be initiated and completed in the order listed below. The availability of UIF datasets, which influence the order and timing of model development, are noted.

River Basin	Unimpaired Inflow Datasets
1. Saluda	To be developed
2. Edisto	To be developed
3. Broad	Available through 2006; To be updated to 2013
4. Pee Dee	To be developed; North Carolina portion not yet developed by others
5. Catawba	Available through 2012 to Lake Wateree Dam; To be updated to 2013
6. Santee	To be developed
7. Savannah	Will be available through 2013 (Georgia is currently updating)
8. Salkehatchie	To be developed

This order may be altered depending on various factors, including data availability. One such factor is the timing of the development of UIF datasets in support of hydrologic basin models in North Carolina, including the Lumber and Yadkin – Pee Dee basins. Modeling in North Carolina's Lumber River Basin, which is contiguous with the Pee Dee in South Carolina, is tentatively scheduled to begin in early 2015 (Tom Reader, pers. comm., September 2014). It is unclear when the unimpaired flow dataset in the Lumber, which is being completed by others, will be available. Similarly, unimpaired flows in North Carolina's Yadkin – Pee Dee basin are not yet available. North Carolina has been evaluating development of a combined Yadkin – Pee Dee and Catawba hydrologic model, which may also commence in early 2015, depending on available funding (Tom Reader, pers. comm., September 2014).

Model development is preceded by the collection of data to both support the baseline models and build the unimpaired inflow datasets. Because of the project's relatively short duration, data collection for all river basins has already begun and will continue through the middle of 2015, with initial emphasis on the Saluda, Edisto, and Broad.

Once the data necessary to support unimpaired inflow and baseline model development has been collected, these tasks will commence. River basin models will be developed in parallel, through use of multiple modeling teams. The generalized project schedule is presented in Figure 10-1. Anticipated model delivery dates will be identified in early 2015, following completion of the pilot model of the Saluda Basin.

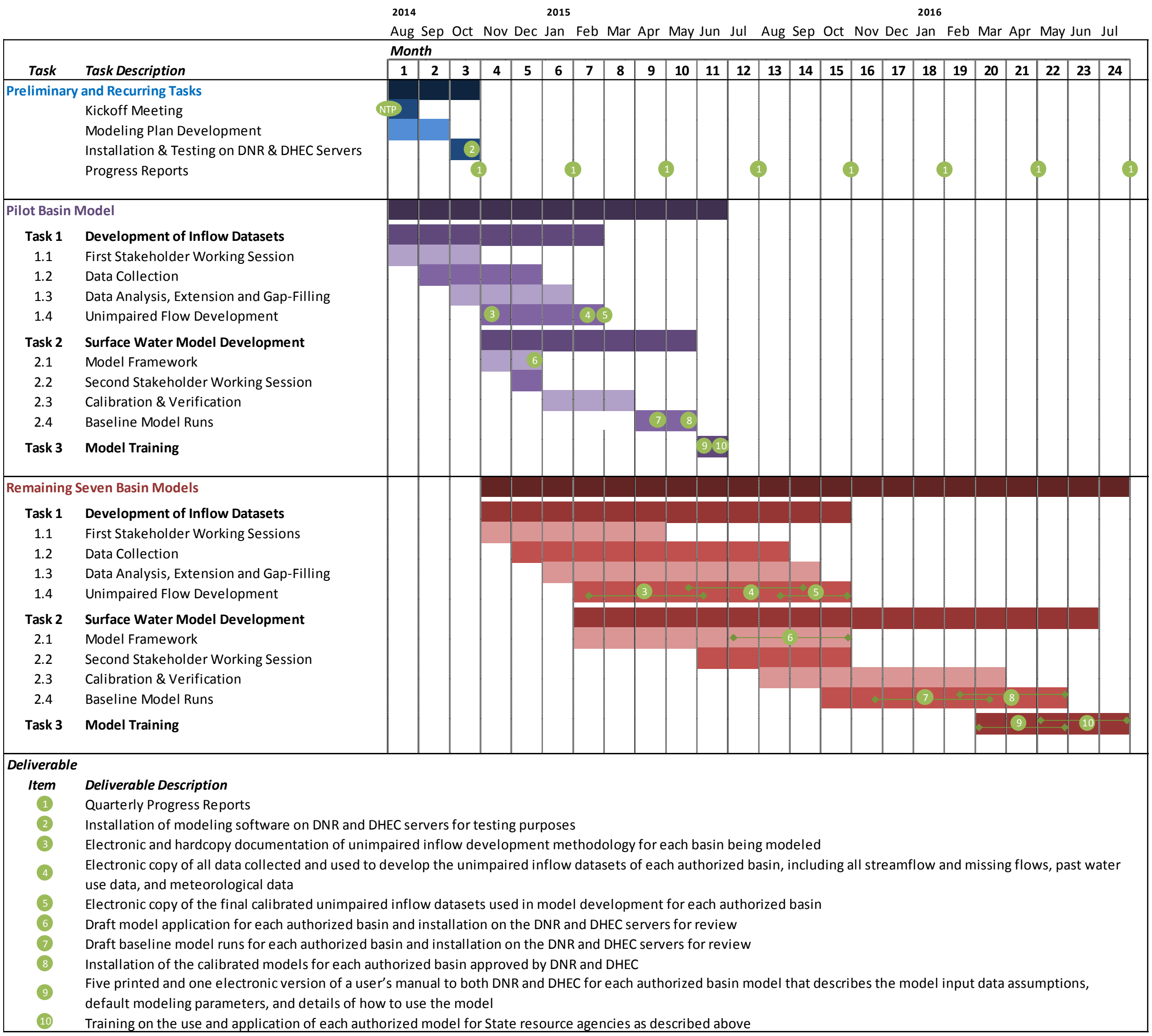

Figure 10-1. Project Schedule

10.2 Model Delivery

Delivery of each river basin model to DNR and DHEC will follow a step-wise process, beginning with the delivery of UIF dataset methodology and culminating with training on each model for DNR and DHEC staff. The major deliverables are listed chronologically for each model at the bottom of Figure 10-1. The following steps are anticipated with regard to model delivery for each basin:

1. The model framework (the physical representation of the basin, including node/object locations) will be provided to DNR and DHEC for review and approval.

2. A calibrated draft model representing baseline conditions will be provided to DNR and DHEC for review and comment.
3. A final model representing baseline conditions, addressing DNR and DHEC comments, will be provided for installation on DHEC servers.
4. Basin-specific user manuals and model training will be provided to DNR and DHEC. Training will focus on the overall functionality of SWAM, as well as specific details of each model.

To allow for portability and support multiple users, SWAM was designed to operate on a desktop environment, be freely distributable, and not rely on third-party software other than the universally-used Microsoft Excel. It can also be web-enabled to allow for remote access to multiple users. Several web-enabled options are available to provide access to SWAM for both internal users (DNR and DHEC) and external users (consultants, academia, utilities, etc.). SWAM is currently anticipated to be deployed using Citrix. This approach, as well as several alternative approaches, will be discussed with DNR and DHEC prior to selecting a final approach for providing access to each river basin model for external users.

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CDM Smith