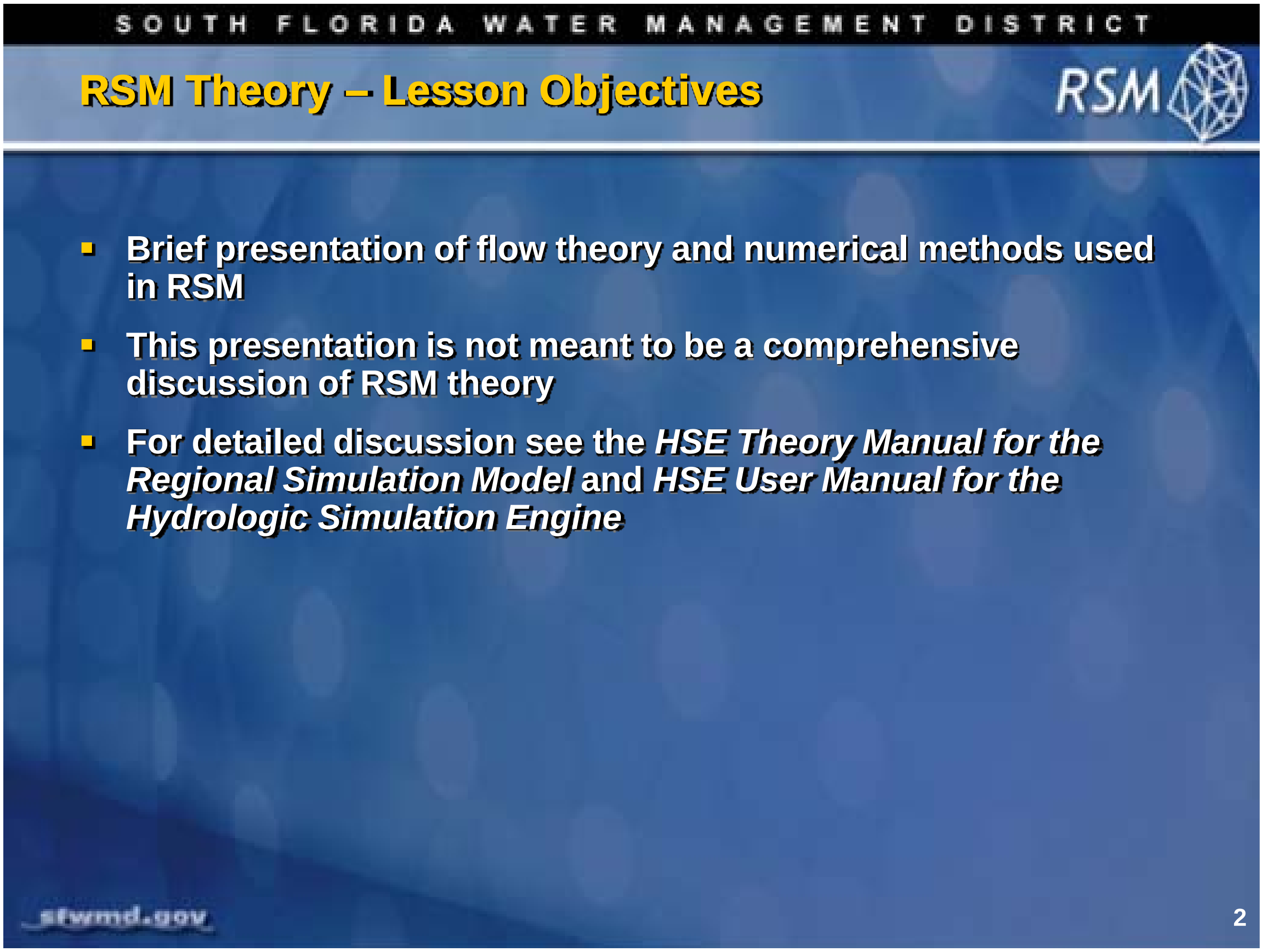
Lecture 2: RSM Theory Numerical Solution

An overview of the transport theory and numerical methods used in the Regional Simulation Model is appropriate to understand how the model works, including the model constraints and limitations.

NOTE:

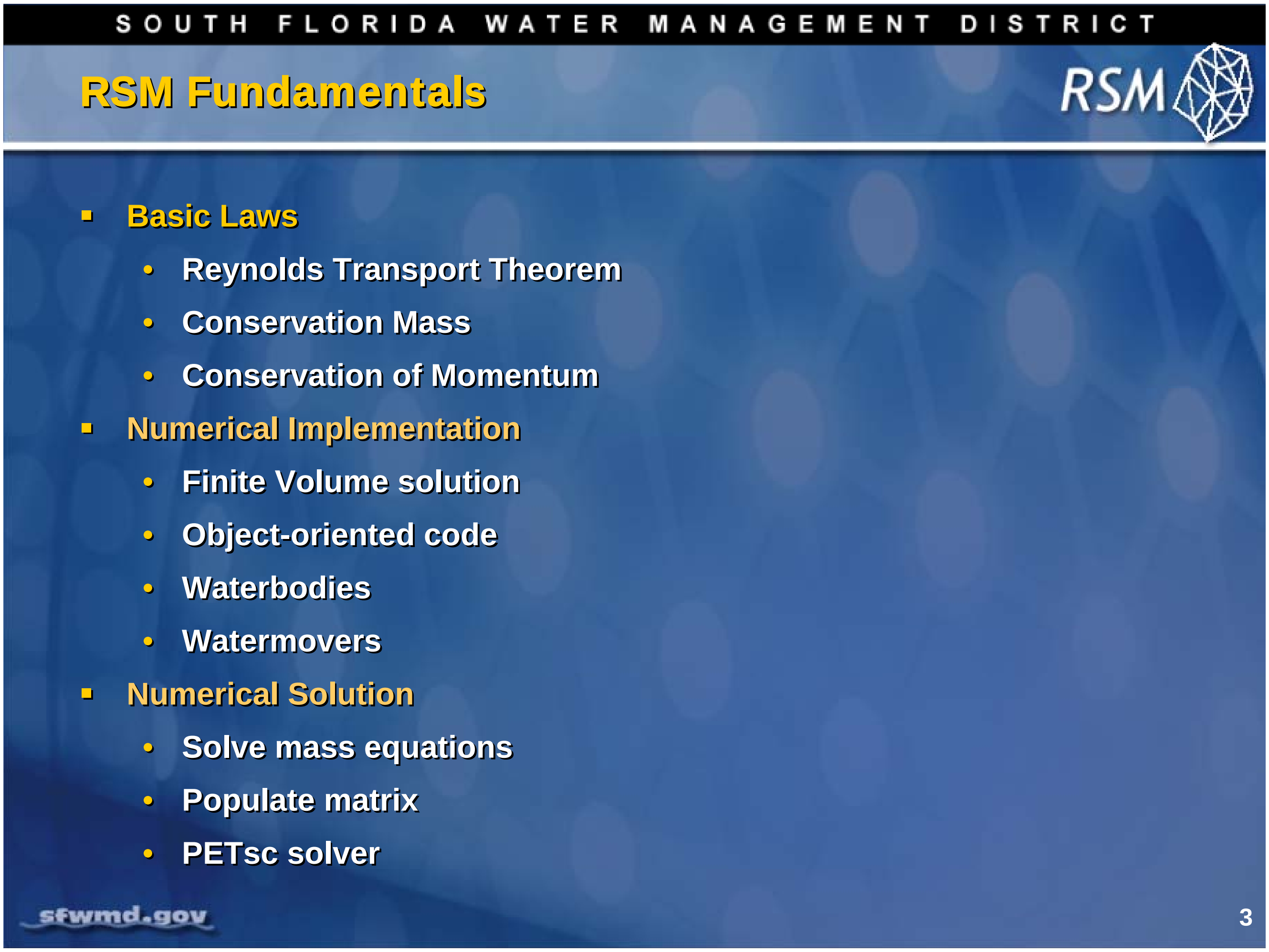
Additional Resources

The HSE Theory Manual can be found in the labs/lab2_BM2 directory.



Session Objectives

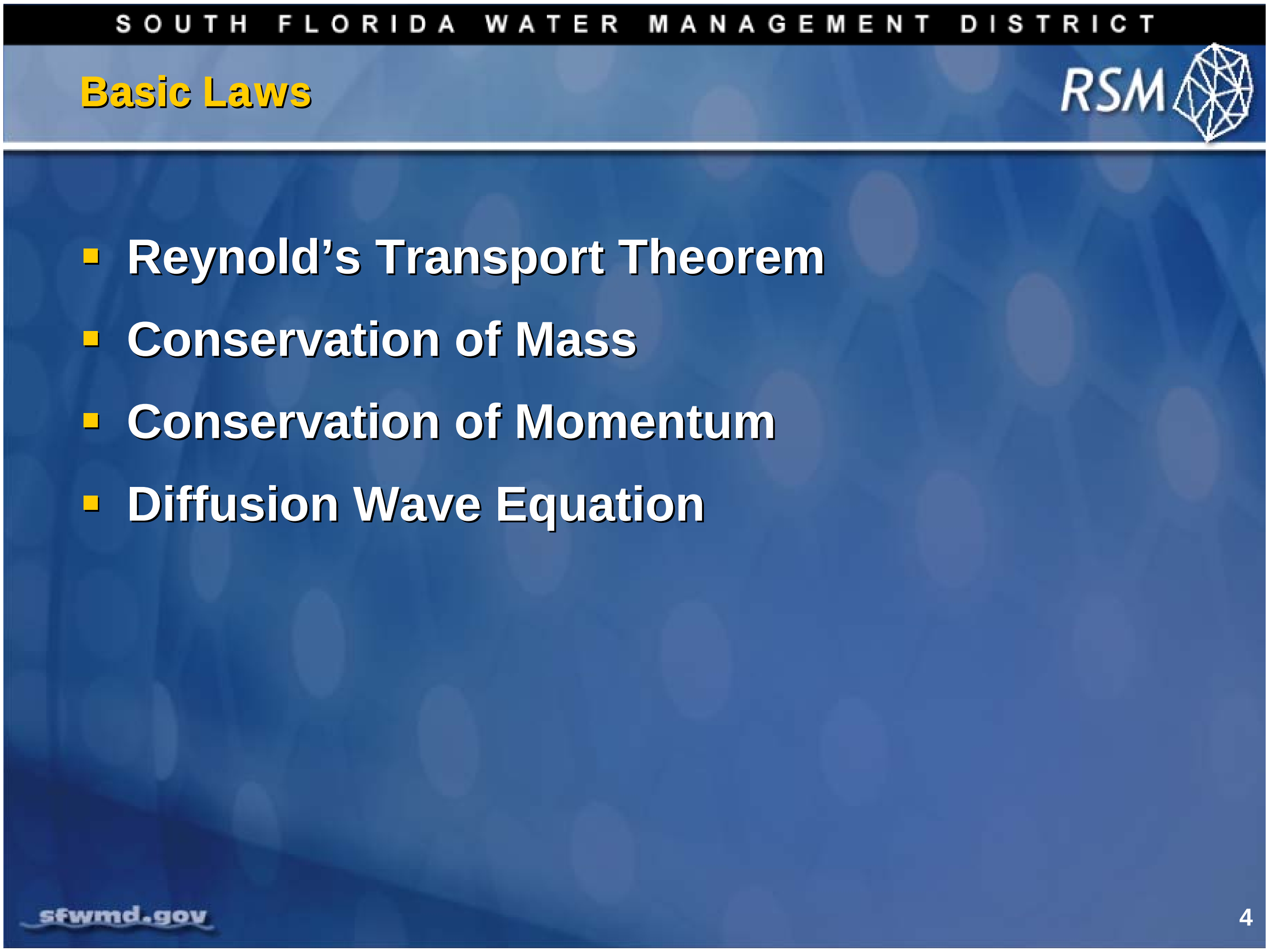
This discussion presents the critical elements of the theory underlying the Regional Simulation Model (RSM). It includes both the transport theory and the numerical methods theory, highlighting the key elements necessary to understanding the structure of the RSM. This lecture does not replace the information available in the appropriate texts, journal articles or course documentation.



The fundamental components of the RSM fall into three categories:

1. Basic physical laws
2. Finite volume implementation
3. The numerical solution of the physical laws through the finite volume method

The RSM is a simple model that solves the transport of water consistent with the conservation of mass and momentum, subject to several limiting assumptions, through the application of the Reynold's Transport Theorem. This methodology is discussed in detail in the HSE Theory Manual and several papers by W. Lal.



The mathematical basis for the RSM is derived from the Reynold's Transport Theorem applying the laws of the Conservation of Mass and Conservation of Momentum. The water flow can be modeled using the Diffusion Wave Equation with the appropriate simplifying assumptions.

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Reynold's Transport Theorem

RSM

$$\frac{D\mathbf{N}}{Dt} = \frac{\partial}{\partial t}\int_{cv} \eta\rho dv + \int_{cs} \eta\rho(\mathbf{E}\cdot\mathbf{n})dA$$

- **N** - arbitrary extensive property, vector or scalar (e.g. mass)
- ***η*** - arbitrary intensive property, or property per unit mass, vector or scalar (e.g. concentration)
- **E** - velocity field
- **n** – the normal vector
- ***dv*** - volume element
- ***dA*** - surface area

Chow et al. (1988)

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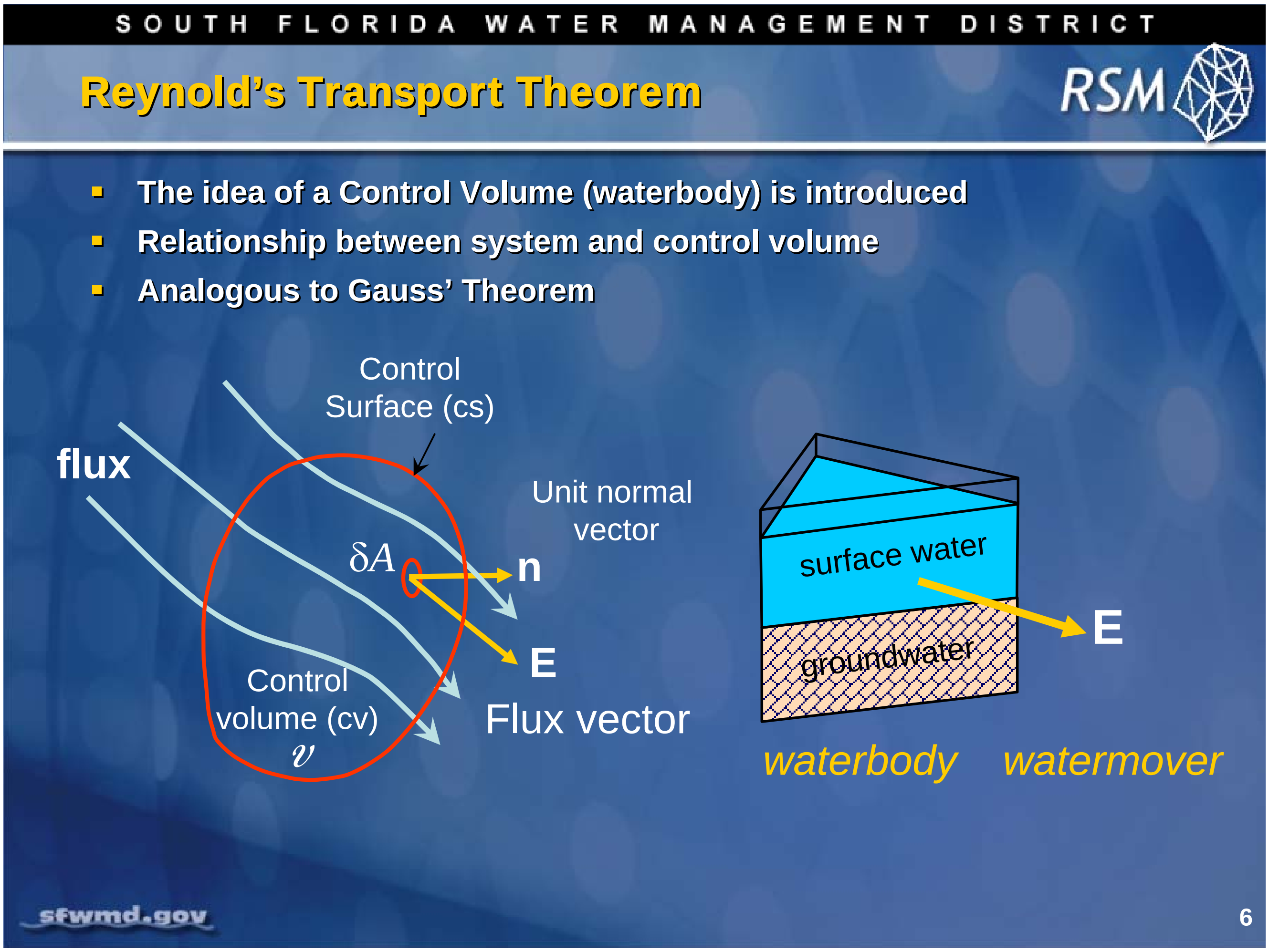
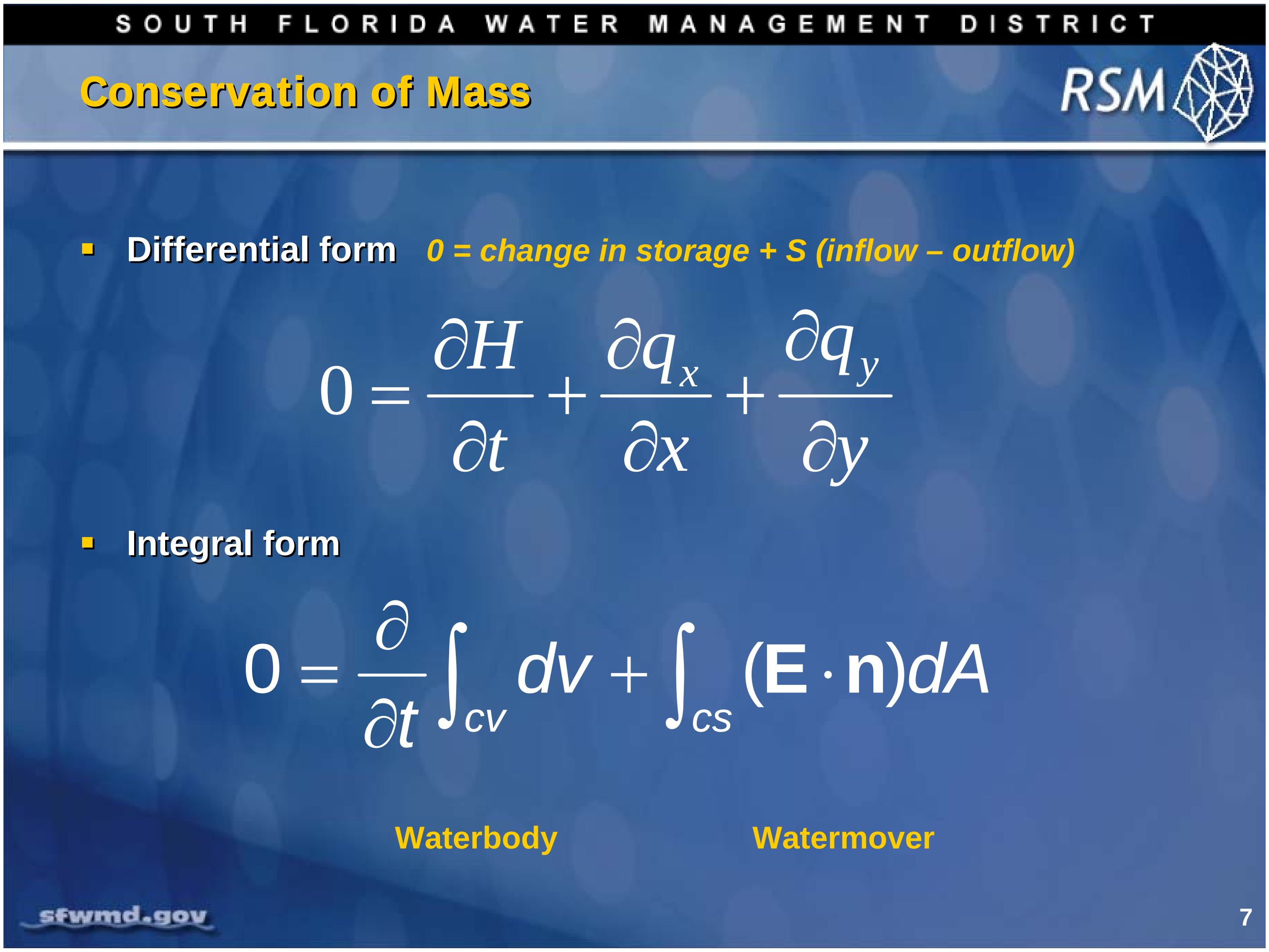
The Reynold's Transport Theorem is the fundamental theoretical basis for the Regional Simulation Model. The theorem states that the change in any extensive property is the sum of the change in the material within a control volume (cv) and the sum of the material crossing the surface of that volume (cs).

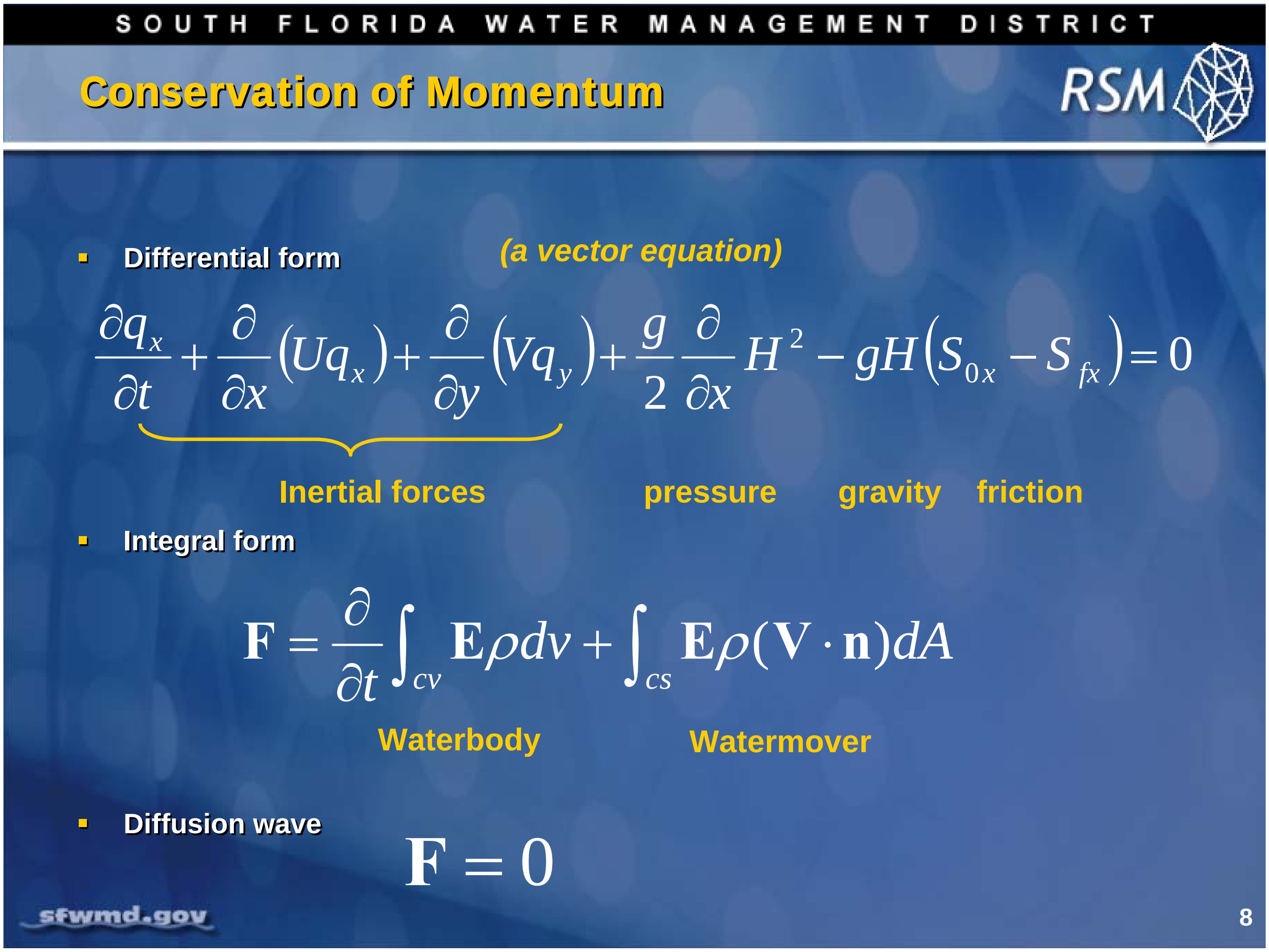


The Reynold's Transport Theorem is applied to a defined Control Volume with a defined Control Surface within a known flux field. The flux across the surface of that Control Volume is equal to the change in storage within the Control Volume.

The Reynold's Transport Theorem is applied to the elements of the RSM. The change in the water content of a waterbody is equal to the flux across the surface as calculated using watermovers. The RSM is composed of a set of waterbodies and watermovers that describe flow in the domain.

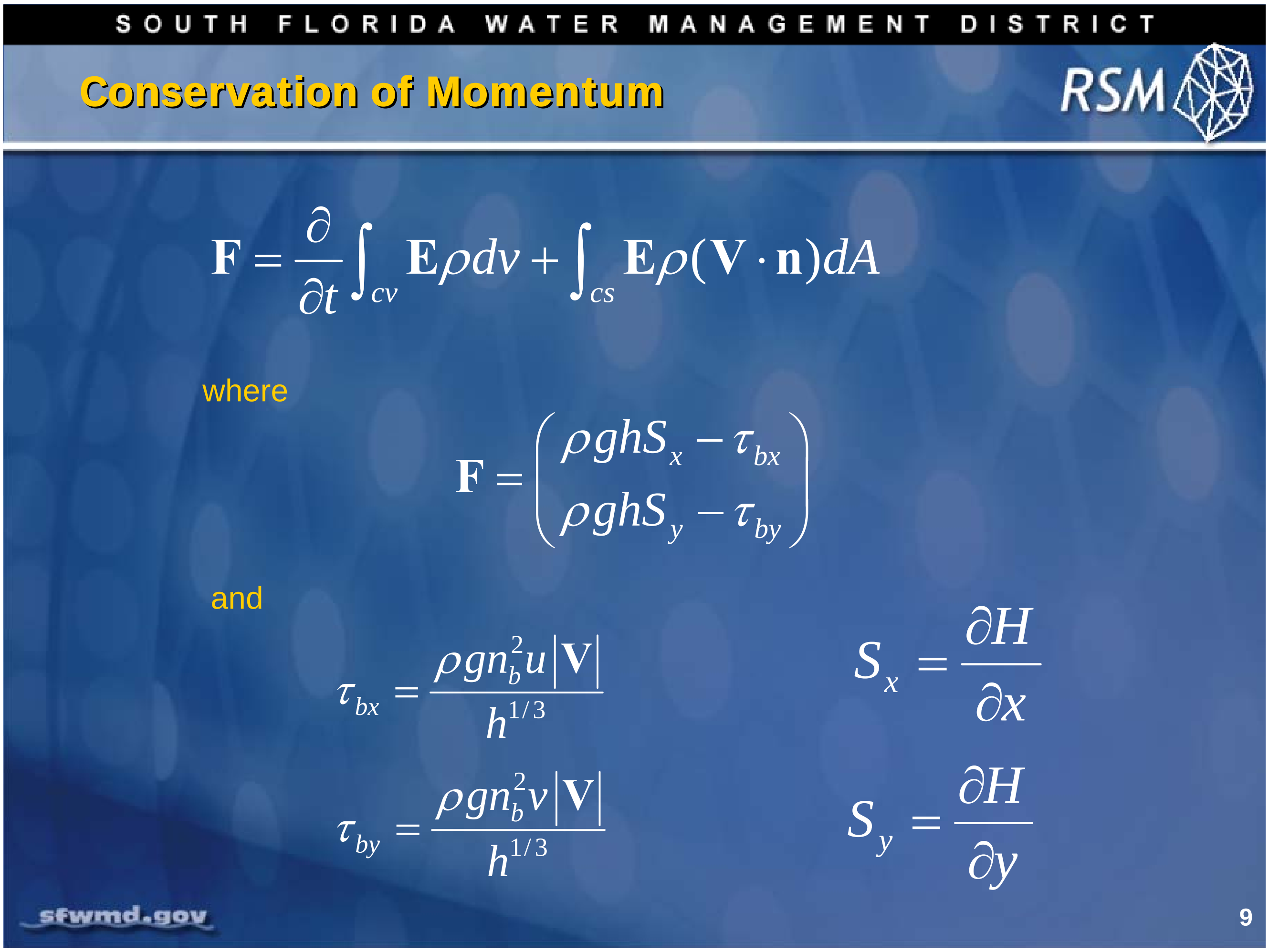


The Conservation of Mass can be expressed in the differential form where the Change in Volume, or head for a unit area over time, is equal to the sum of the inflows and outflows. Expressed in the integral form, it is solved in the finite volume method.

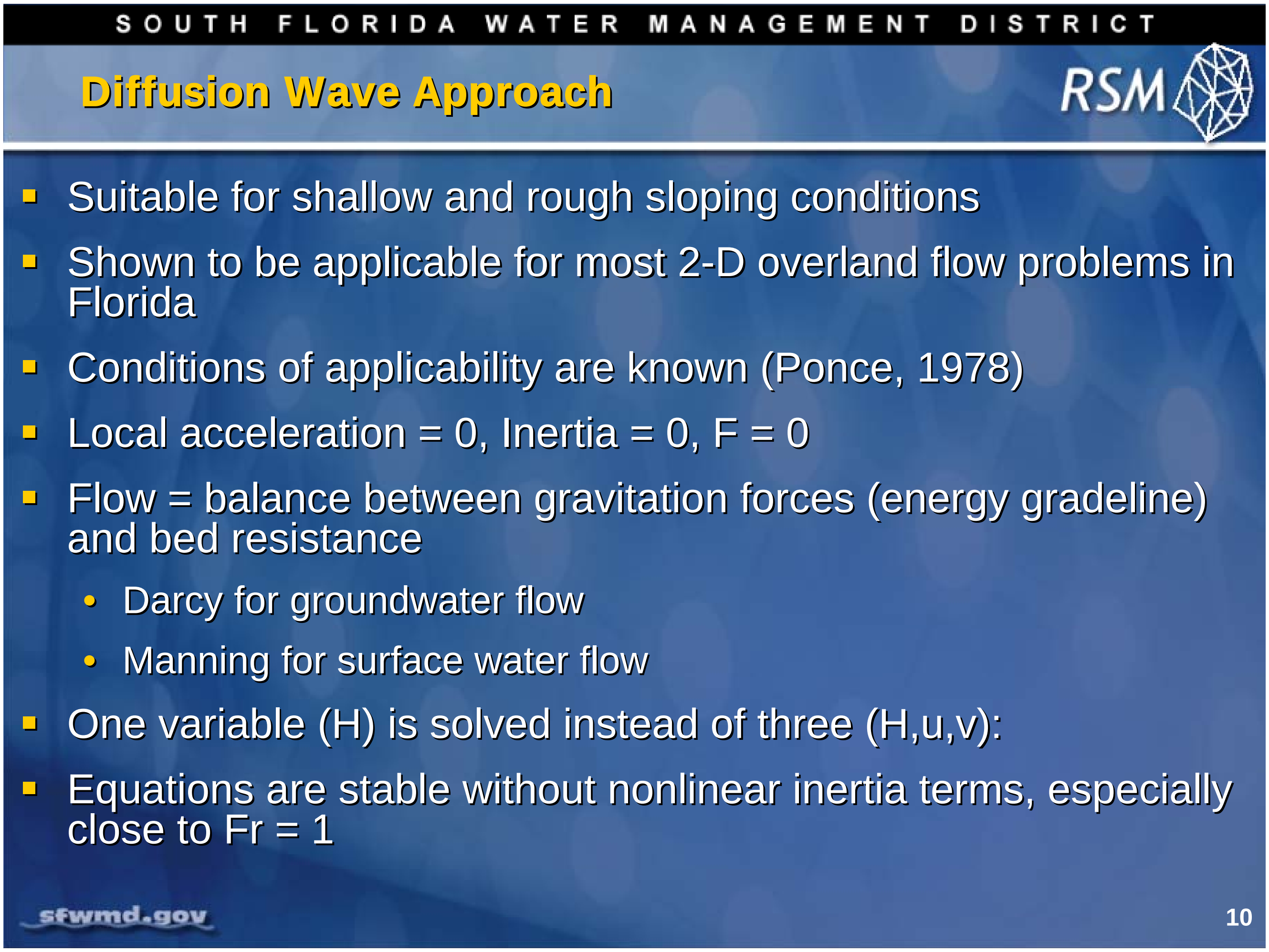


The Conservation of Momentum is typically presented in the differential form with the various forces acting on the Control Volume. For the Diffusion Wave approximation the inertial and pressure terms of the Conservation of Momentum equation are neglected.

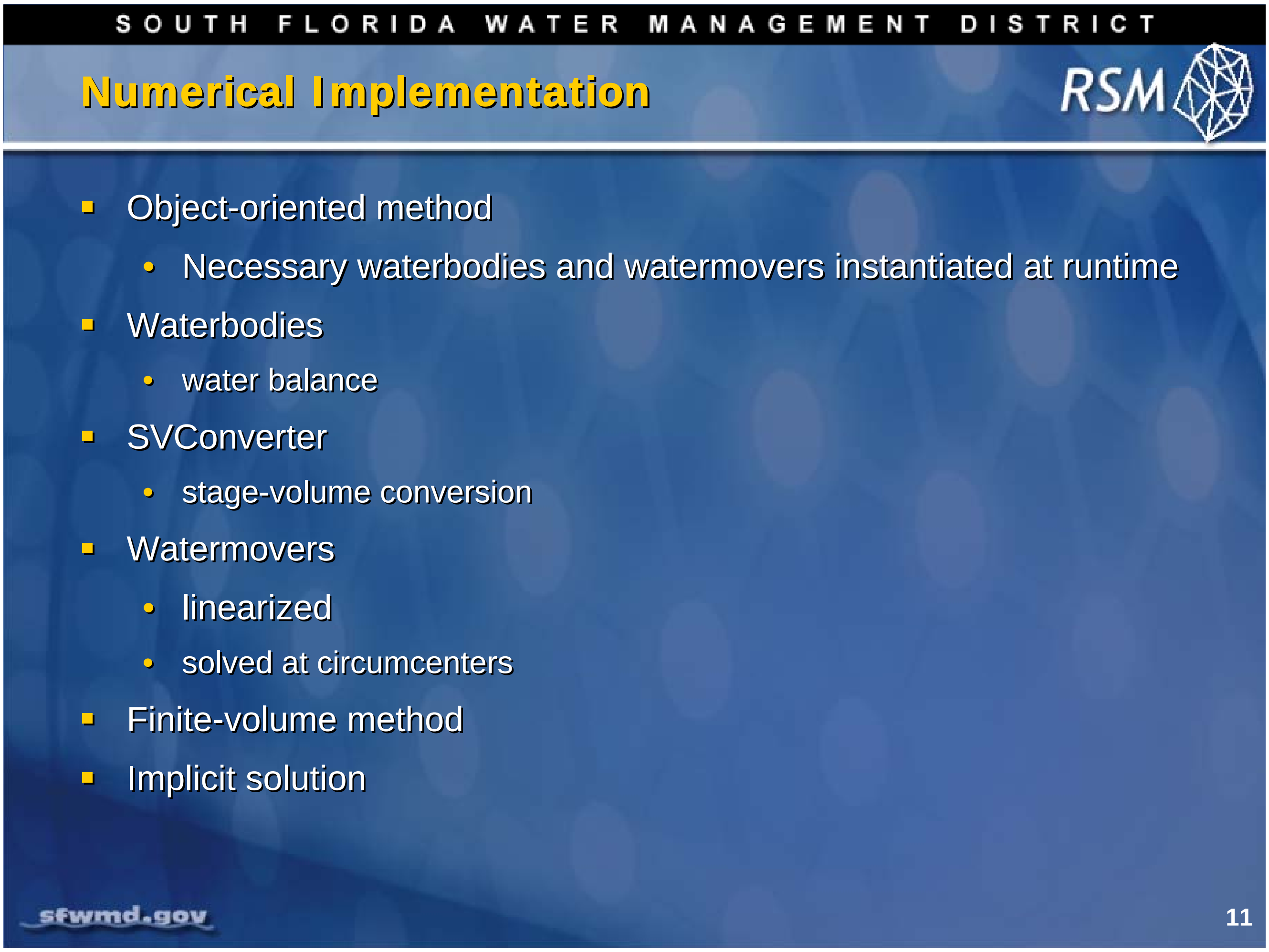
The Conservation of Momentum is solved in the Finite Volume method using the integral form. For the Diffusion Wave solution, the source of momentum change equals zero and the gravity head is equal to the friction head.



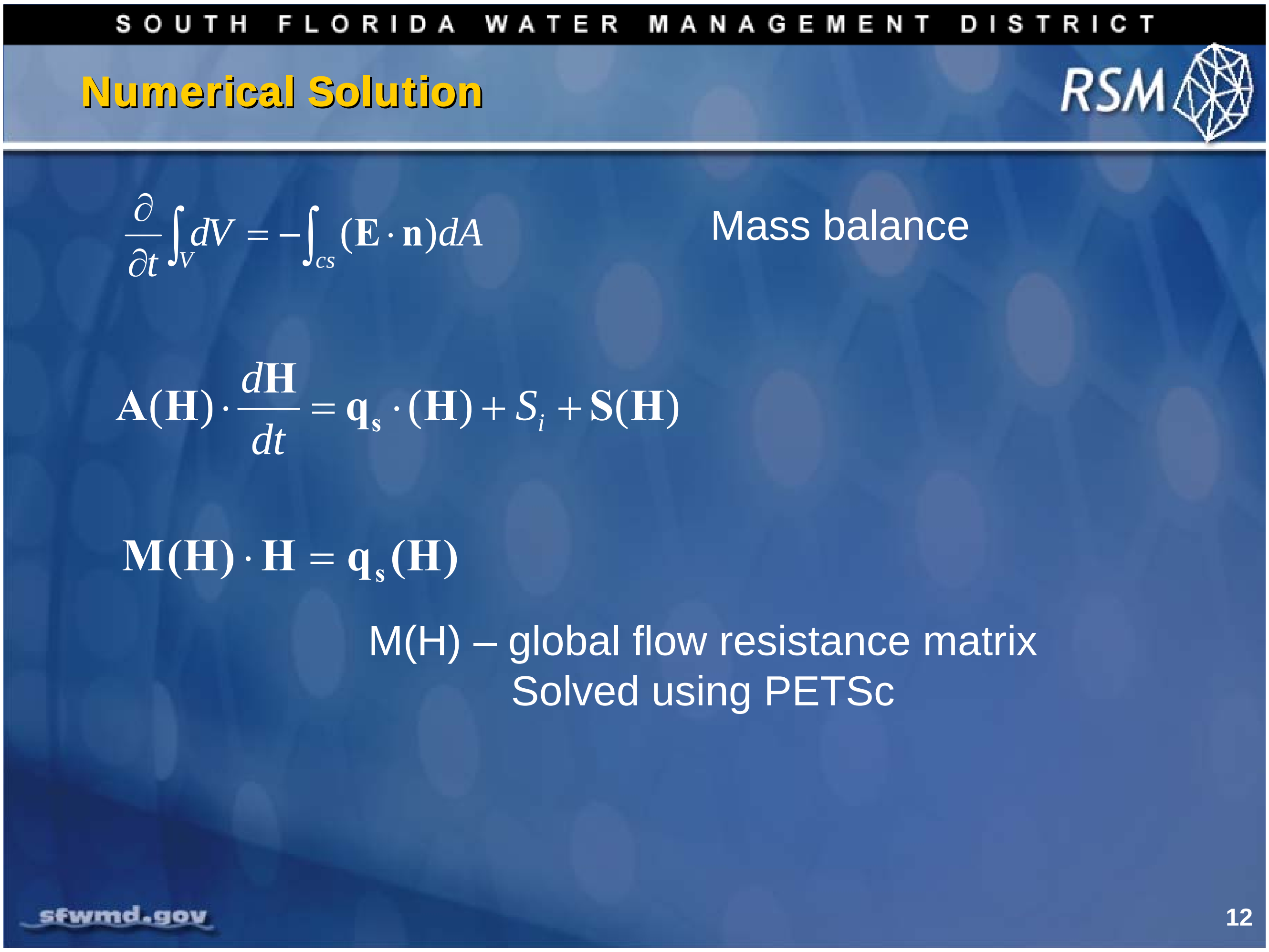
The Conservation of Momentum consists of two components: the gravitational head and the change in momentum due to the bed friction. The friction losses are described here for surface water flow.



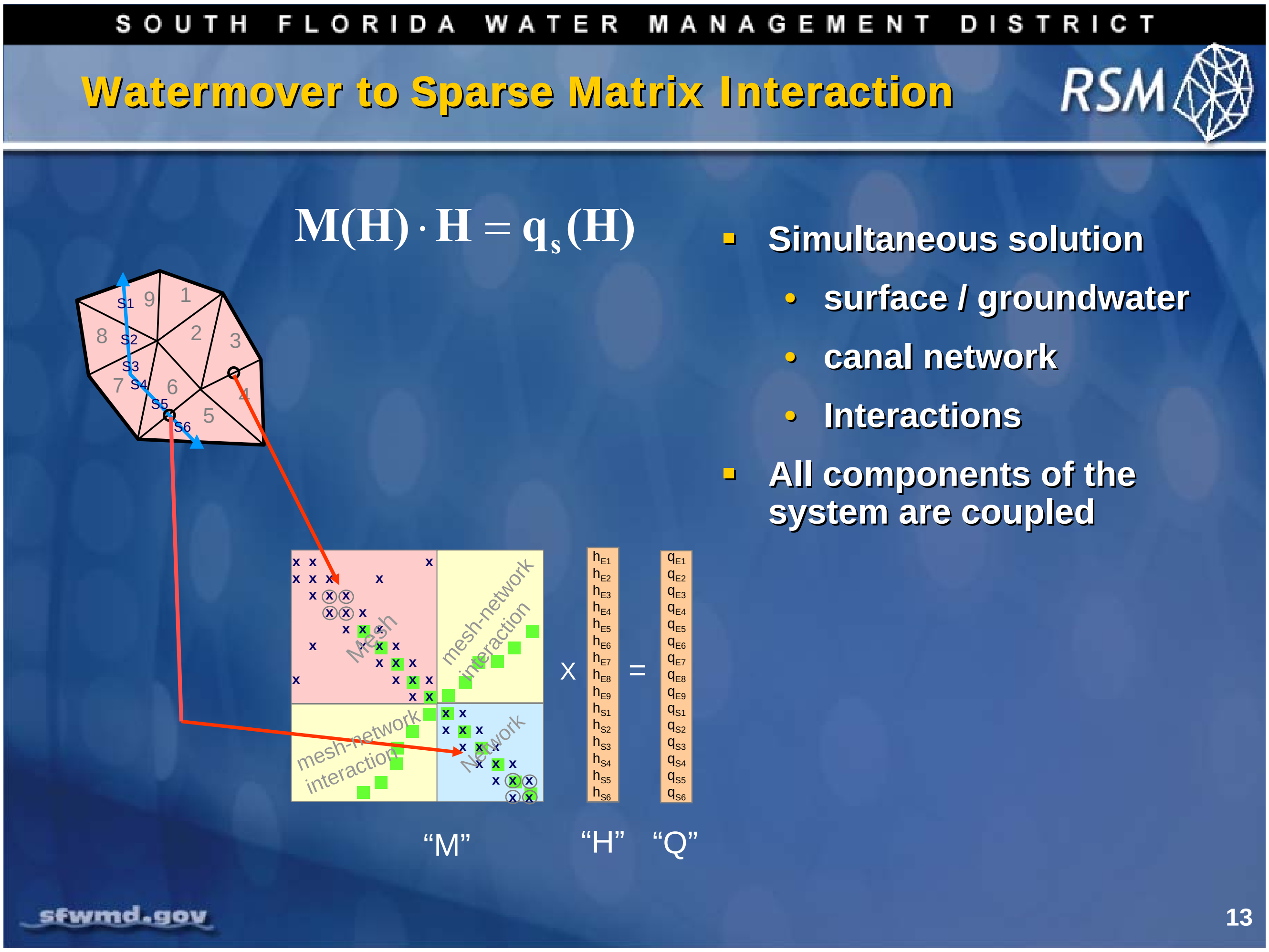
The diffusion wave equation is appropriate for south Florida conditions where the changes in flow depth are small and slowly varying. The conditions of applicability defined by Ponce (1978) are met for the RSM and this has been demonstrated by the RSM over a range of conditions that occur in south Florida. For these conditions the local acceleration and inertia terms are considered negligible. Flow then becomes a balance between gravitational forces and the bed resistance. This formulation results in Darcy flow for groundwater and Manning type flow for 2D surface water flow. The flow equations are stable near Froud number = 1; without the nonlinear terms the equation is stable up until it fails.



The numerical solution of RSM follows from the construction of waterbodies and watermovers using object-oriented C++ code. An RSM is constructed when a group of waterbodies and watermovers is instantiated as objects at run time such that only the necessary objects are constructed. The SVconverter (stage-volume) is used to convert between the volumetric water balance in the waterbodies and the solution of the diffusion wave equation which is solved for head or D_{head}. The flow equations are solved using linearized watermovers applied to the circumcenters of adjacent cells in the 2D mesh and among the other waterbodies in the model. The integral form of the diffusion equation is solved using an implicit solution for the finite volume method. The RSM uses the PETSc sparse matrix solver for implicit solution. The details of this approach will be presented in the following section.



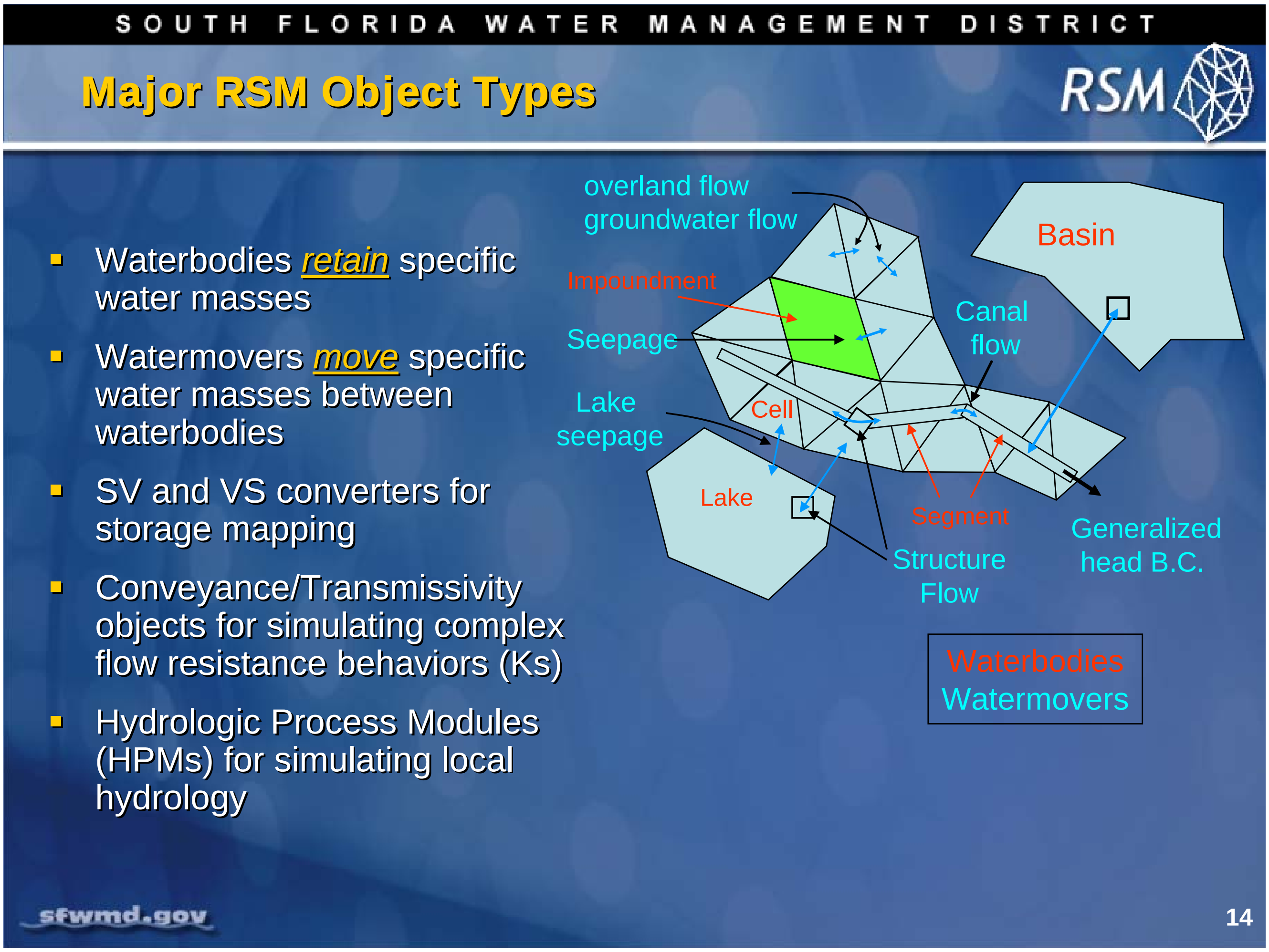
The numerical solution for the mass balance equation is presented in vector form of the ordinary differential equation. The terms of the left-hand side is the volume of water in each waterbody as an effective area which is a function of head and the change in head over time. The terms of the right-hand side are the head dependent flows between waterbodies, head independent flows as boundary conditions and head dependent boundary conditions. In the RSM, this relationship is rewritten to obtain a flow resistance matrix, or stiffness matrix, when multiplied by the head vector equals the flow vector. This equation is solved implicitly to obtain the heads for each timestep.



The numerical solution for the RSM consists of calculating the known flows from heads and boundary conditions and entering those into the flow vector, Q, for each time step and constructing the resistance matrix, M.

The flows represent coupled equations for each sending and receiving pair of waterbodies. These coupled equations are used to populate the matrix in the PETSc sparse matrix solver which is used to estimate heads.

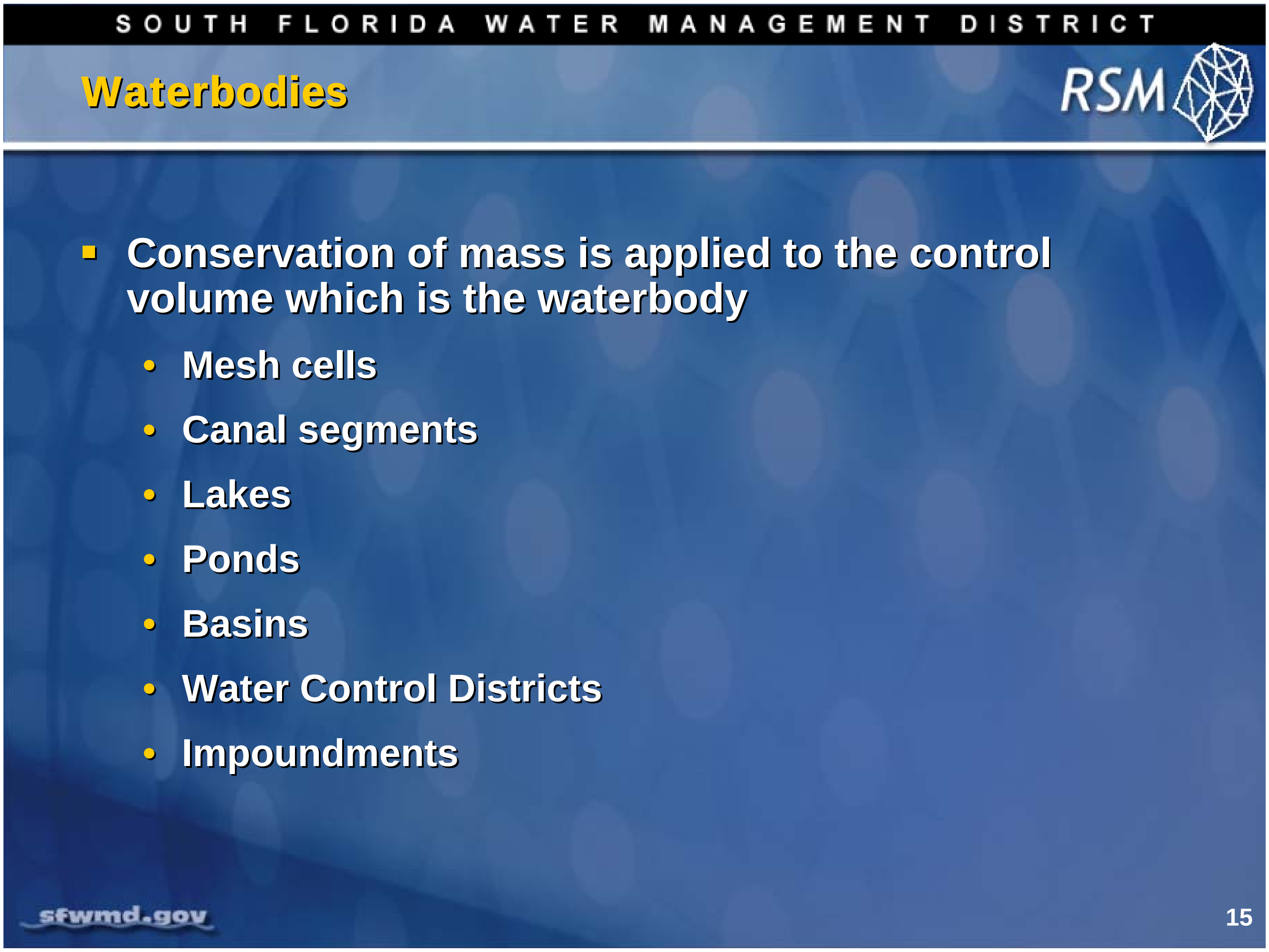
Essentially, the RSM code is designed to calculate values to populate the solver for each timestep. This will be discussed in more detail during the watermover discussion.



In the RSM, the waterbodies and watermovers are instantiated as objects at run time. There are several types of waterbodies that model the 2D domain and canal network as well as simulate different features in the regional water management system.

There are many types of watermovers that move the water between the different waterbodies based on the heads in the system. There are stage-to-volume (SV) and volume-to-stage (VS) converters to relate the water stored in the waterbodies to the water moved by the watermovers.

The flow resistance component of the diffusion wave equation is instantiated from a group of conveyance and transmissivity functions for different flow conditions. The ET, rainfall and local hydrology are implemented through HPMs that are applied to cells, lakes and basins.



There are several types of waterbodies. These include the irregular triangular cells of the 2D-3D mesh that are used to simulate surface water and groundwater movement.

An RSM implementation typically includes a canal network that is composed of individual segments and groups of segments called reaches.

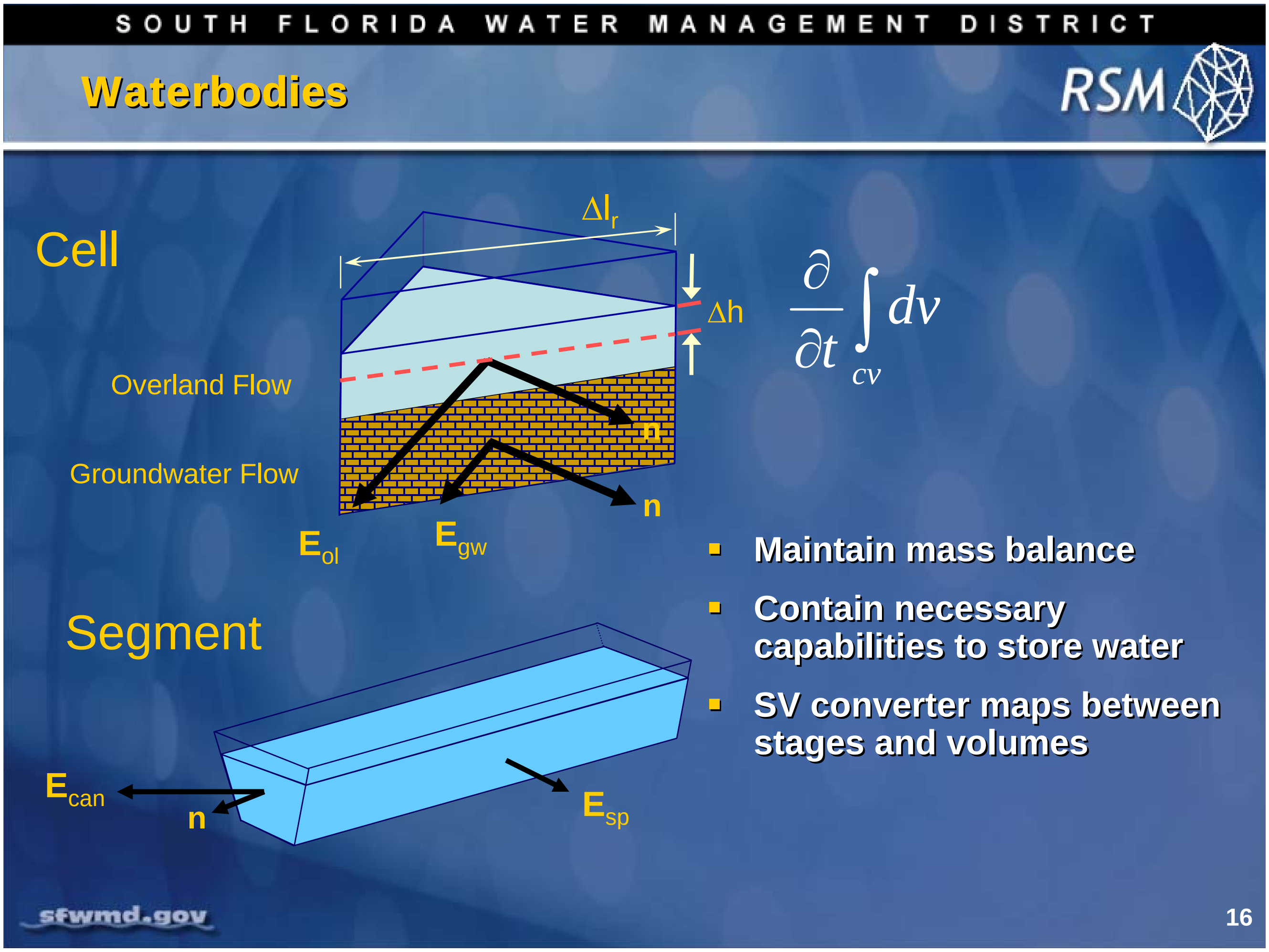
Lakes are waterbodies that are linked to other waterbodies in the RSM through watermovers but the lakes have no specific physical location in the model domain.

Ponds are essentially lakes that occur within a single cell.

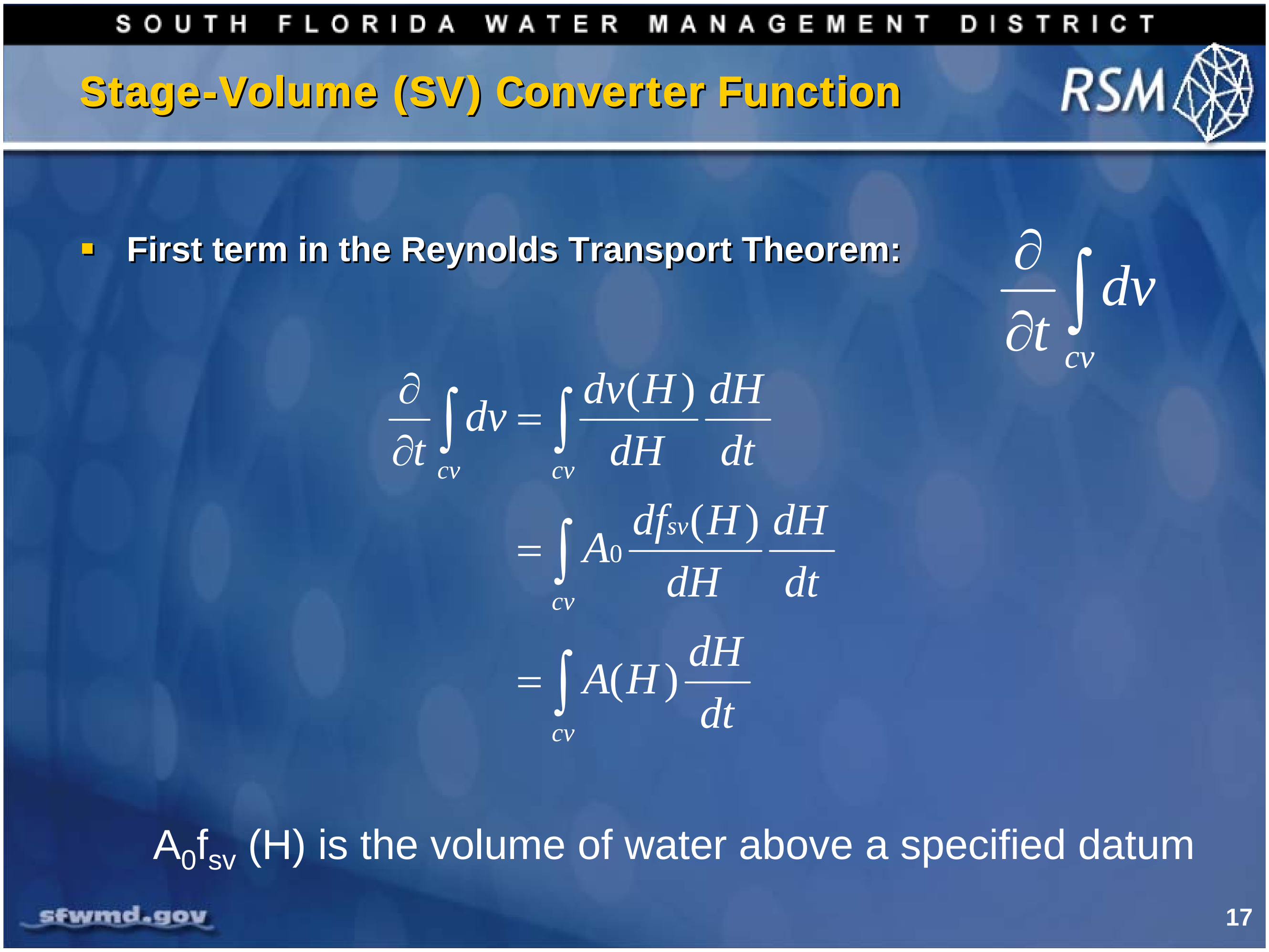
Impoundments are lakes that cover more than one cell and sit on top of the mesh. They are used to simulate stormwater treatment areas (STAs) or reservoirs.

Basins can be used in place of a group of cells to simplify the implementation of the model for solving regional water allocation problems.

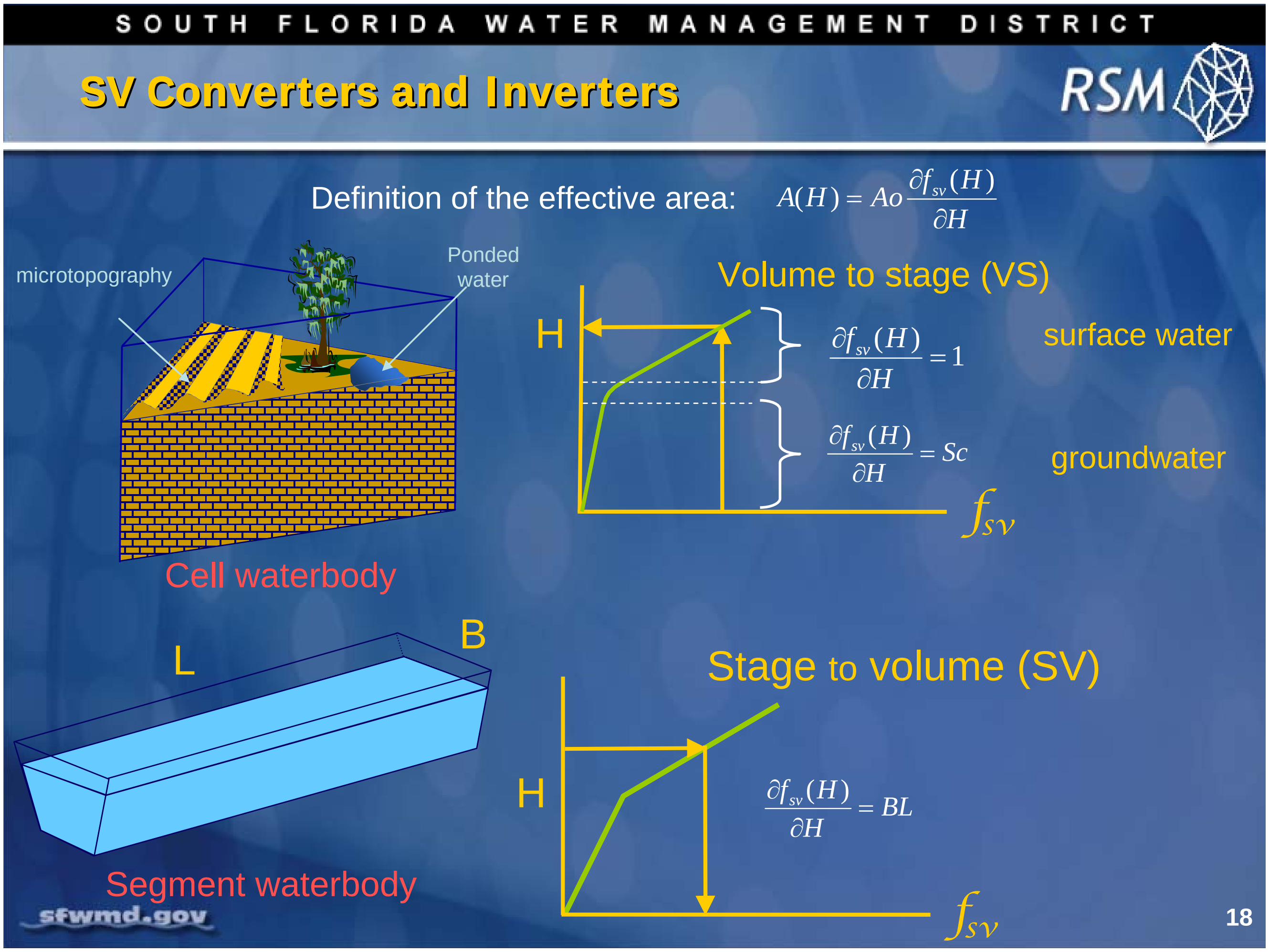
Water Control Districts (WCDs) are a special type of waterbody that simulates the behavior of secondary water management systems that are larger than a cell.



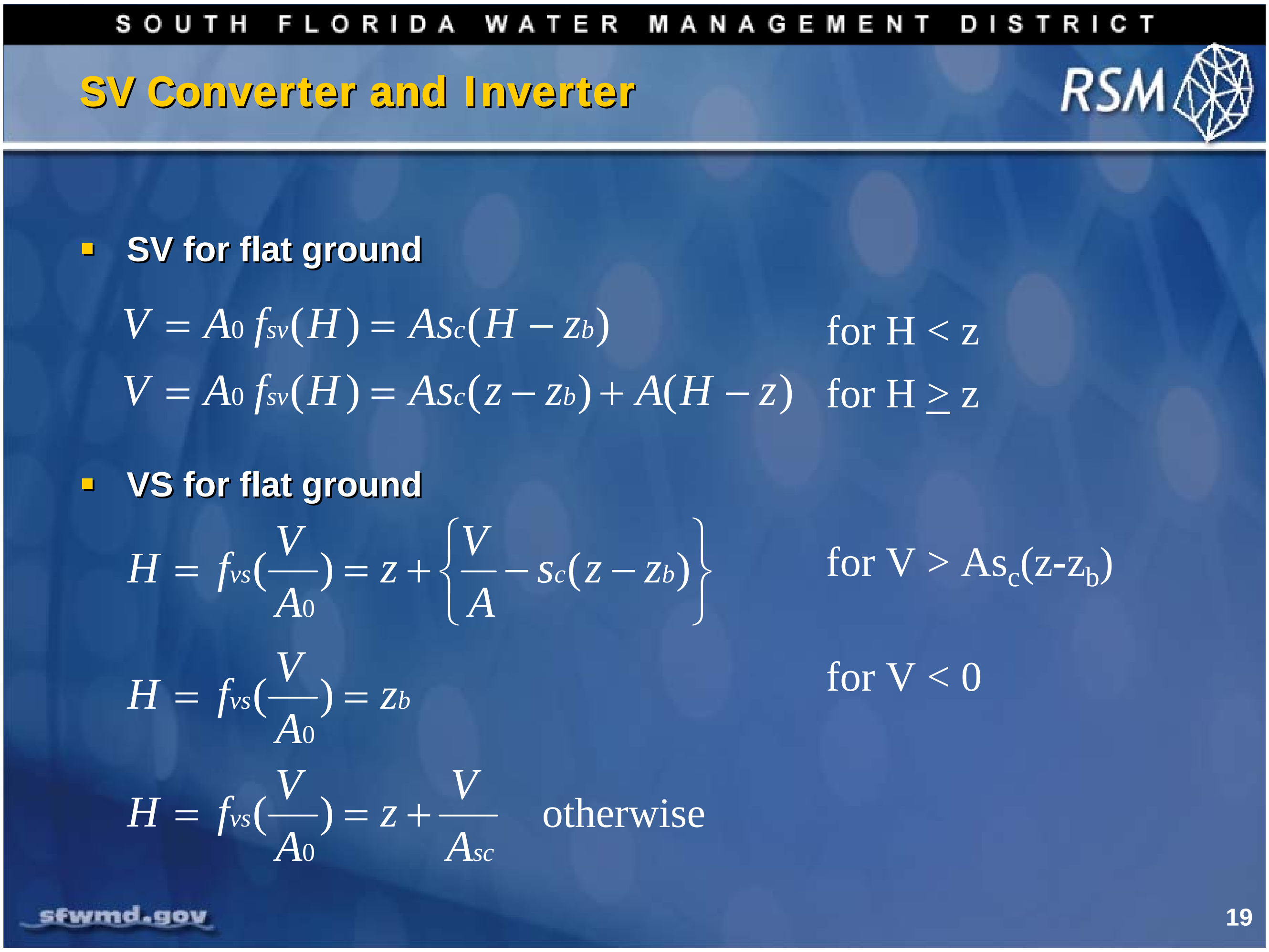
The waterbodies are designed to maintain mass balance for each timestep. The dimensions of the waterbodies are created during the RSM initiation. The SV and VS converters are constructed to convert between stage and volume so that mass balance is maintained. This is true for cells and segments as well as the other waterbody types.



The transport equation is solved in part by solving for the change in the volume over time. The change in volume is a function of the change in head (H) with time multiplied by a function that describes the change in volume as a function of head. This function, f*sv*, is used to translate between the implicit solution for water flow which is calculated in terms of head and the water balance which is calculated in terms of volume. The effective area, *A*(H), which is a function of head, is used in the final matrix solution when solving for H.

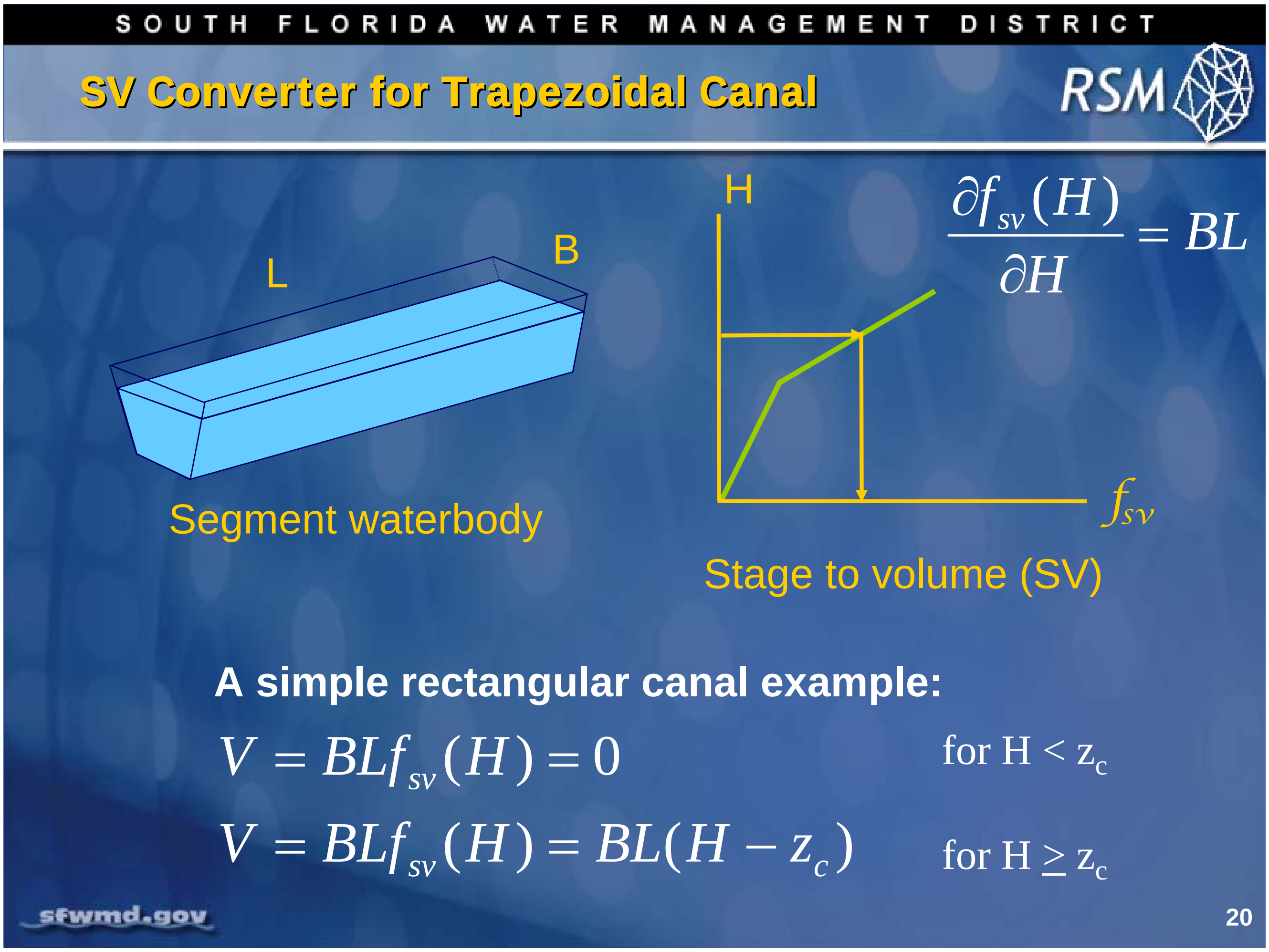


Specific SV and VS converters are constructed for each waterbody. For cells, the converter can be simple if the surface is assumed to be flat. However, there is considerable variation in water yield where there is microtopography and variable soil water storage. In the RSM a piece-wise continuous function is implemented using a lookup table, or rulecurve, to describe the change in yield from pure groundwater, where sc is the specific yield, up to fully flooded land. Similarly, the appropriate converters can be constructed for segments, lakes, basins, impoundments and WCDs.

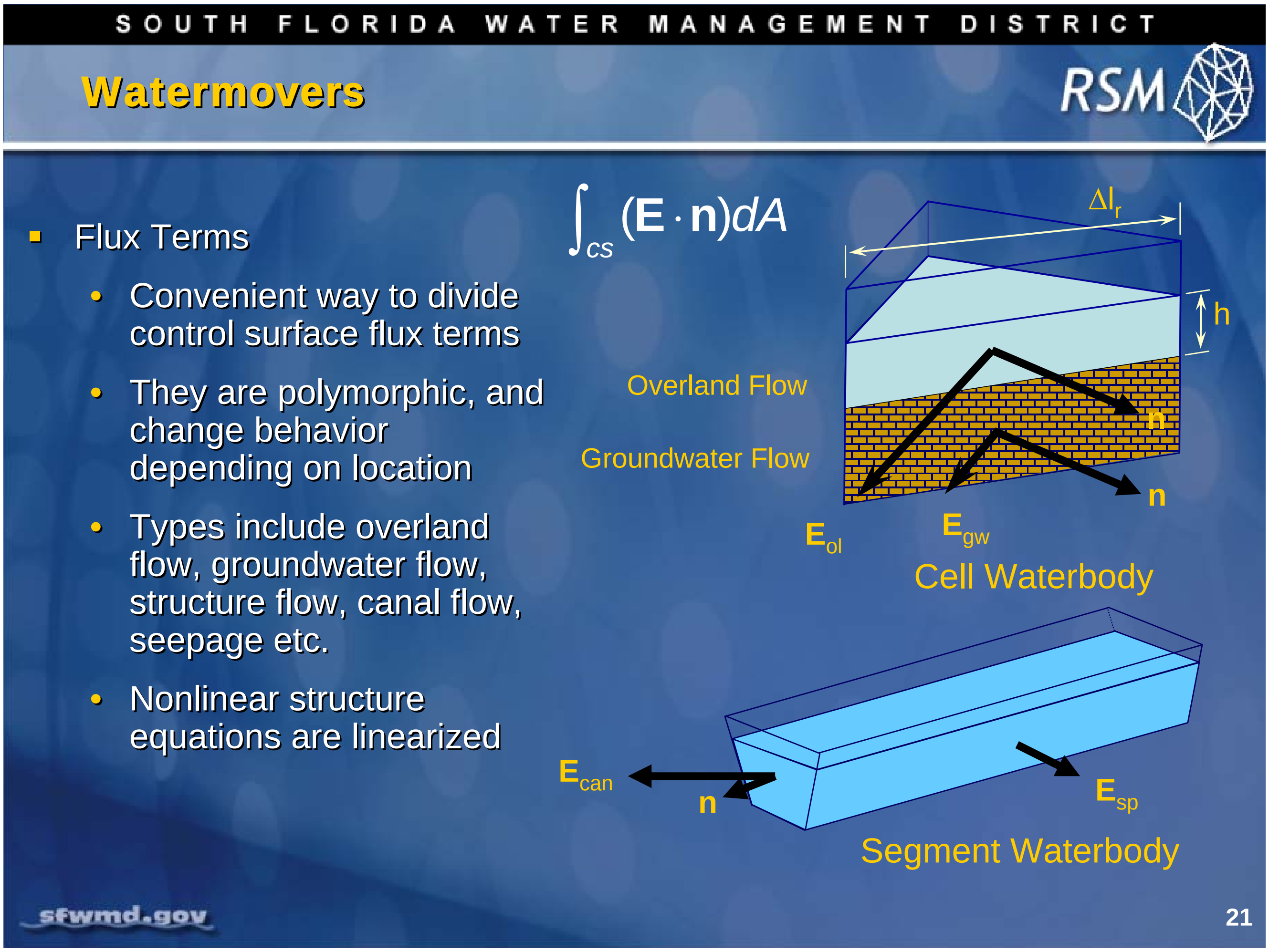


The SV converter is used to calculate volume for the water balance analysis given the head from the implicit solution. The volume values are important outputs from the RSM. The VS inverter is used to convert the volumes calculated from explicit HPM, MSE calculations and boundary conditions into head for input for the implicit solution.

Here are the converter and inverter for flat ground where z is the ground surface and z_b is the depth below ground. The SV and VS functions are more complex where the soil porosity and microtopography are included.



The SV converter for a canal is simpler. Canals typically have rectangular or trapezoidal cross-sections. The RSM does not use other possible canal cross-sections although there is the capability of specifying a parabolic cross-section. Here the SV converter is for a canal and zc is the elevation of the canal bottom.

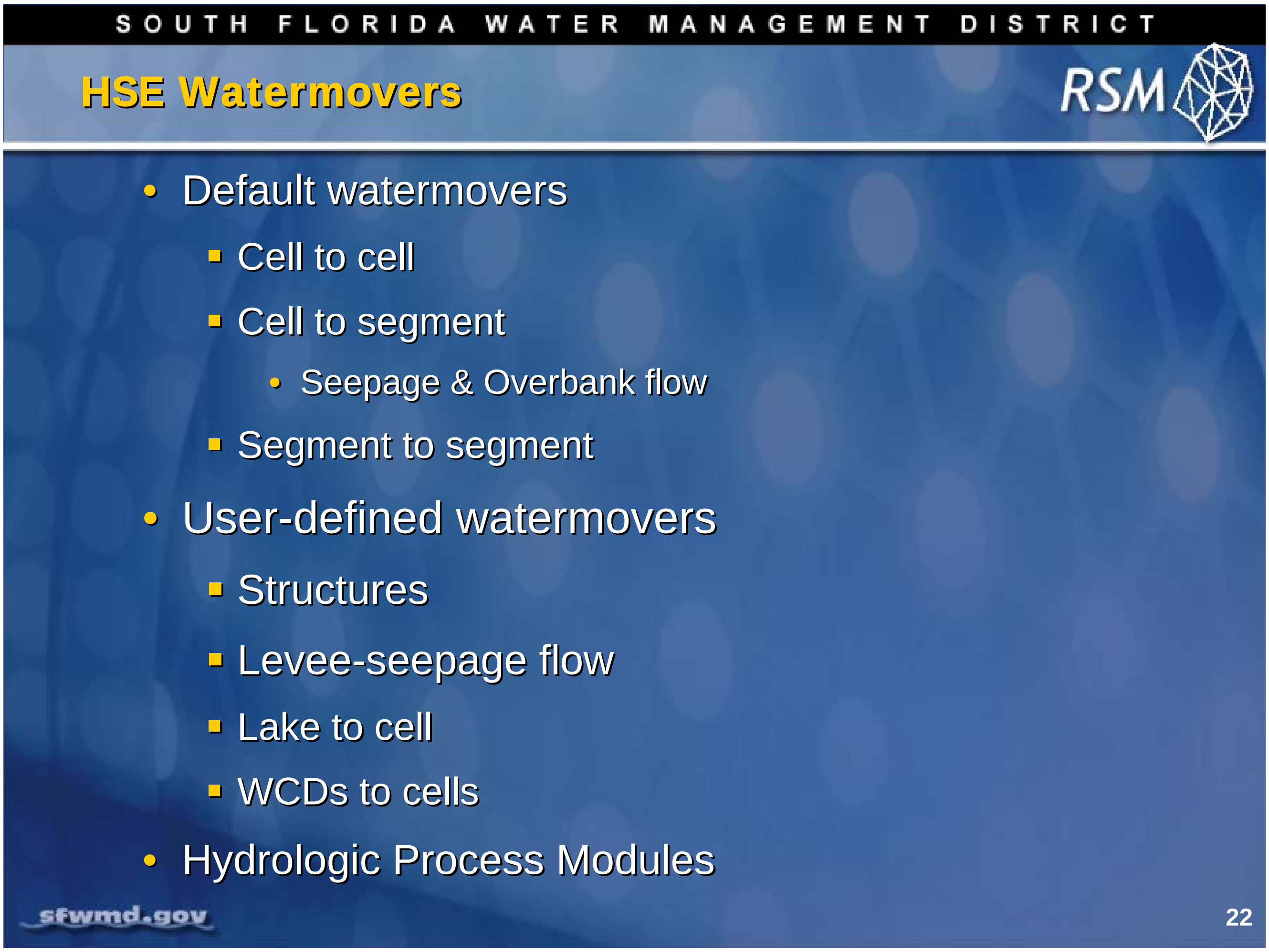


The watermovers describe the content of the second term in Reynold's Transport Theorem. This is the flow of material across the boundary of the control volume normal to the surface.

For the cells, the watermovers consist of groundwater flow and surface water flows. The groundwater and surface water are partitioned by comparing the head to ground elevation at each timestep.

The watermovers can have different parameters depending on location and head. There are many types of watermovers depending on the type of flow that is simulated.

The discharge equations for water control structures are typically non-linear and are made linear for use in the RSM.



The watermovers are implemented to move the water from waterbody to waterbody.

The cell-to-cell, segment-to-cell, and segment-to-segment watermovers are created automatically by the RSM.

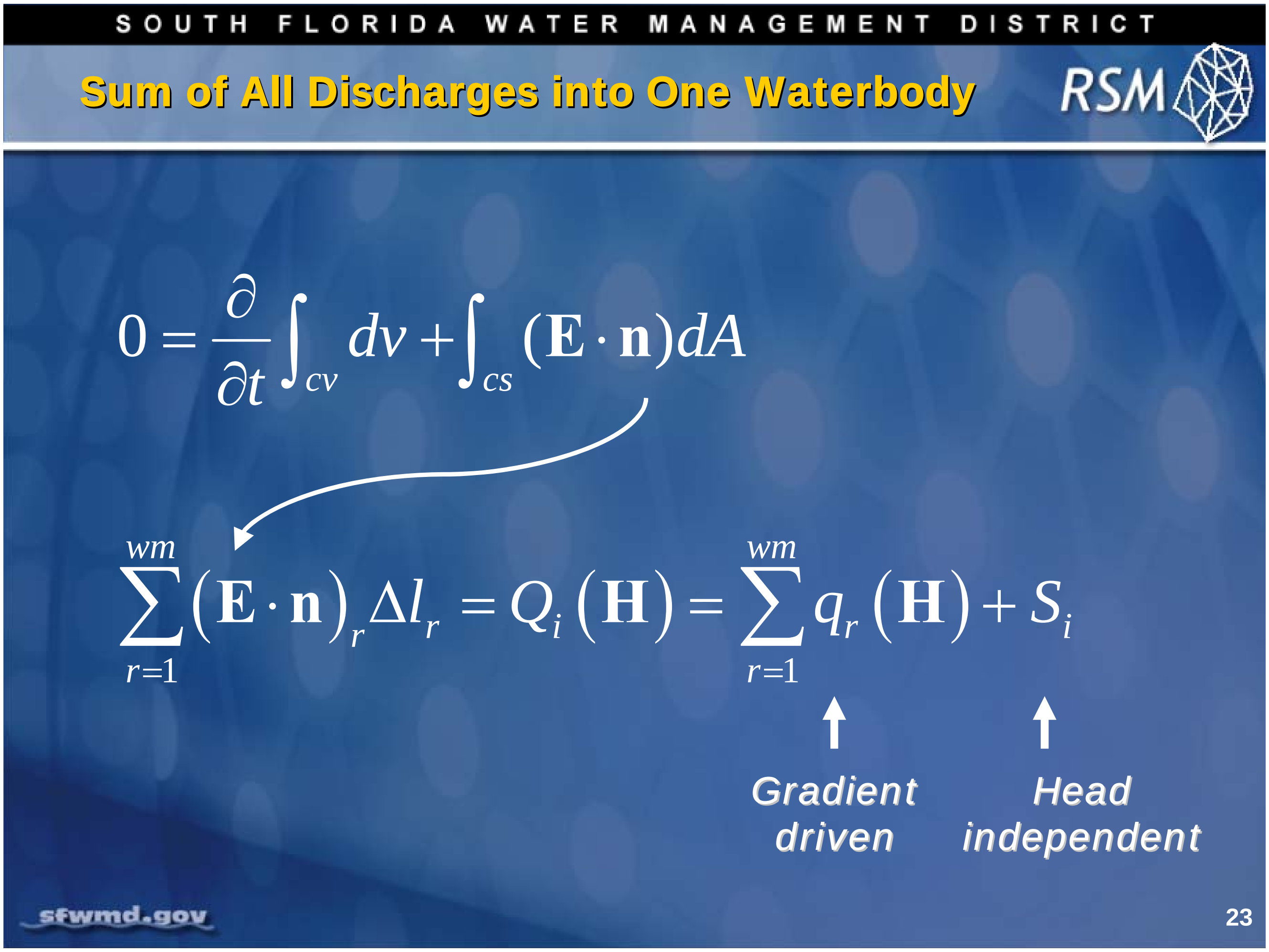
It is possible to create no-flow conditions between cells, segments and cell-segments using specific functions, when necessary.

User-defined watermovers are specified in the XML input file to connect other types of waterbodies.

Structures are a specific group of watermovers that are implemented to simulate physical structures, including: pumps, weirs and culverts.

Given that the RSM is designed to operate on a daily timestep, these structures must be used as carefully specified.

The HPMs are a special subclass of watermovers that are designed to model vertical movement into cells.



The flows defined by Reynold's Transport Theorem can be broken into two terms:

1. Head dependent flows between waterbodies
2. Head independent flows, which are typically boundary conditions such as wells, recharge, and flows along the mesh domain boundaries

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Linearized Water Movers

RSM

$$q_r = (\mathbf{E} \cdot \mathbf{n})_r$$

$$= K_{mn}(H_m - H_n) = \Delta l T_r \frac{H_m - H_n}{\Delta d_{mn}} \left\{ \begin{array}{lll} \text{for } H_m > H_n & \text{and } H_m > z_m & \text{and } H_m > z_n \\ \text{or } H_n > H_m & \text{and } H_n > z_n & \text{and } H_n > z_m \end{array} \right\}$$

$$q_r = K_o + K_m H_m + K_n H_n$$

Surface water

$$T_r = \frac{h_r^{5/3}}{n_r s_r^{1/2}} \qquad S_r = \sqrt{\frac{(\hat{H}_j - \hat{H}_k)^2}{\Delta l_r^2} + \frac{(H_m - H_n)^2}{\Delta d_{mn}^2}}$$

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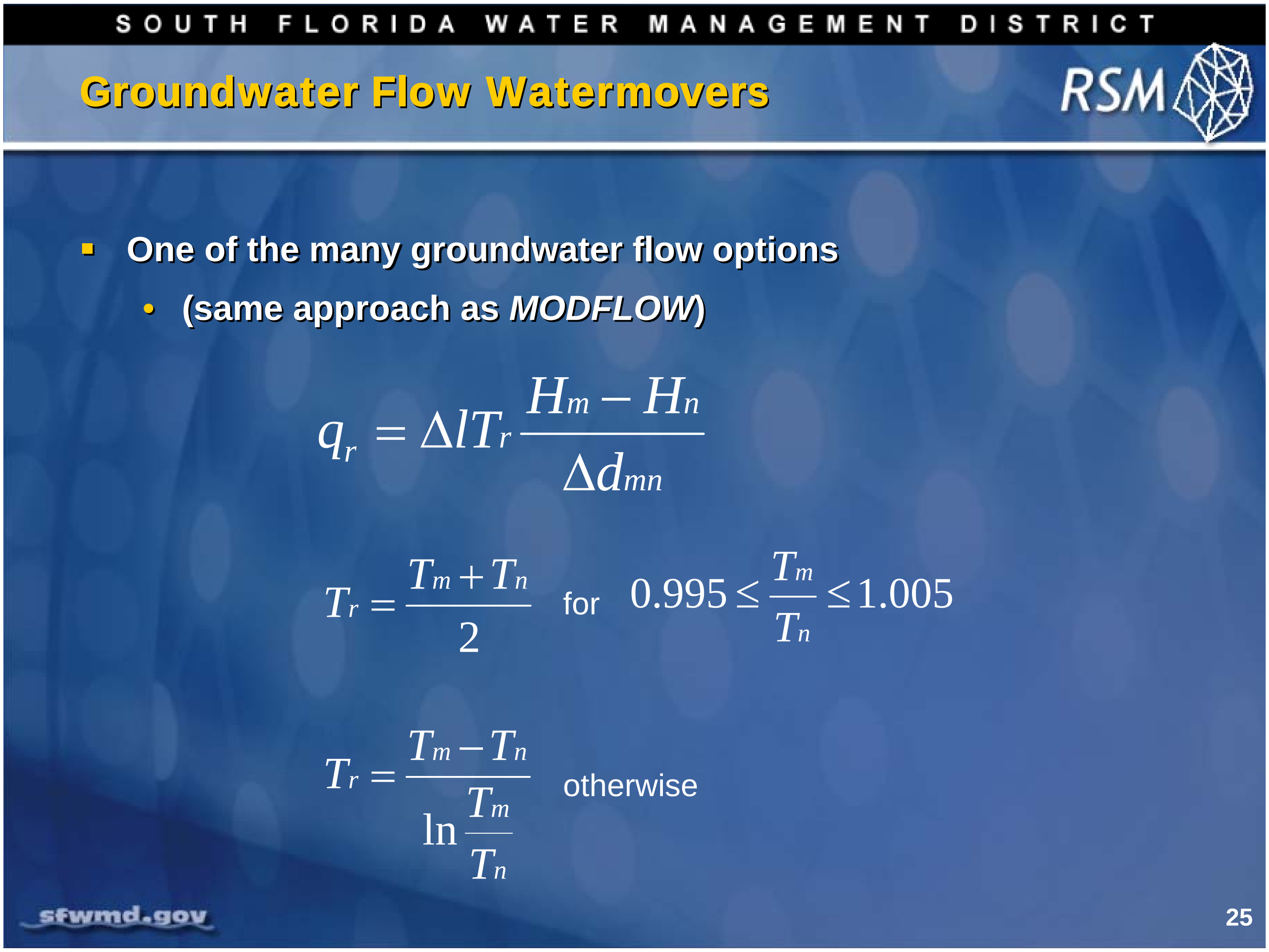
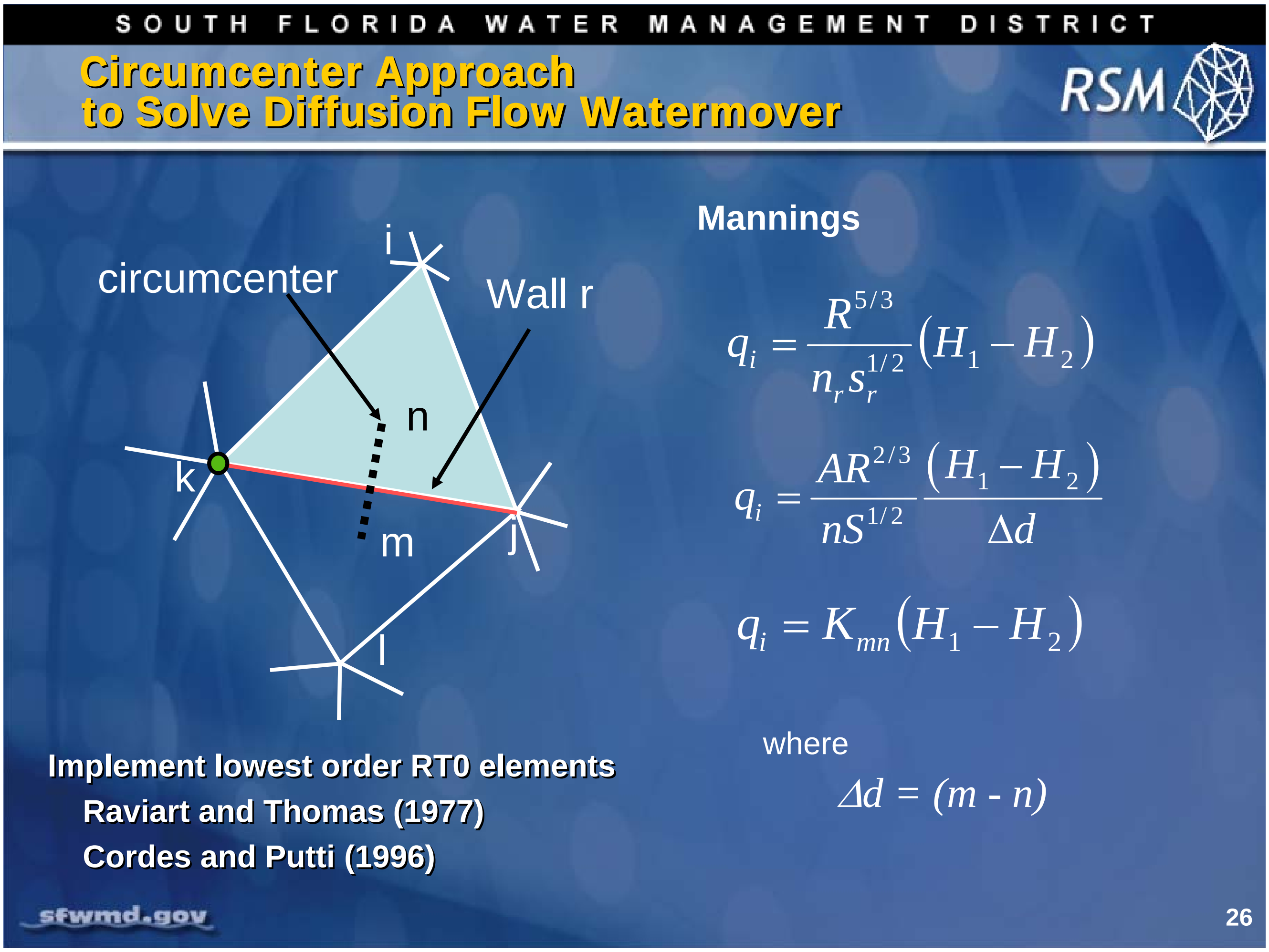
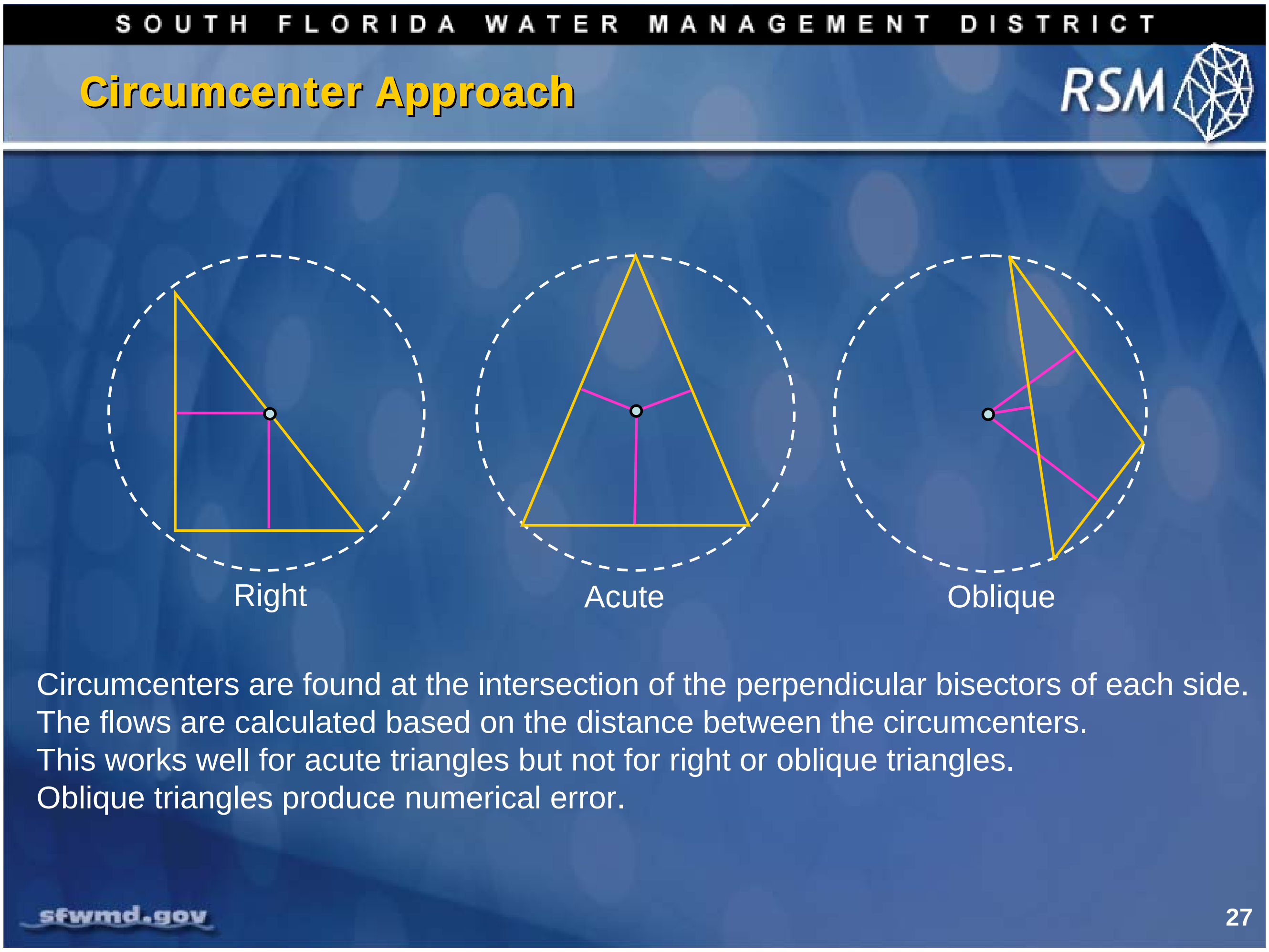
The implicit solution requires the creation of linear watermovers to describe flow between waterbodies. Although the hydraulics are frequently highly non-linear, the flow (q_r) can be approximated by a linear equation in K_o, K_1 and K_2 for small changes in head. This presents the watermover between adjacent cells (m,n) where Dl is the length of the edge and Dd_{mn} is the distance between the circumcenters. In this example, the value of T_r is represented by the Manning Equation. There are many alternative formulations for T_r or K_s to represent watermovers.



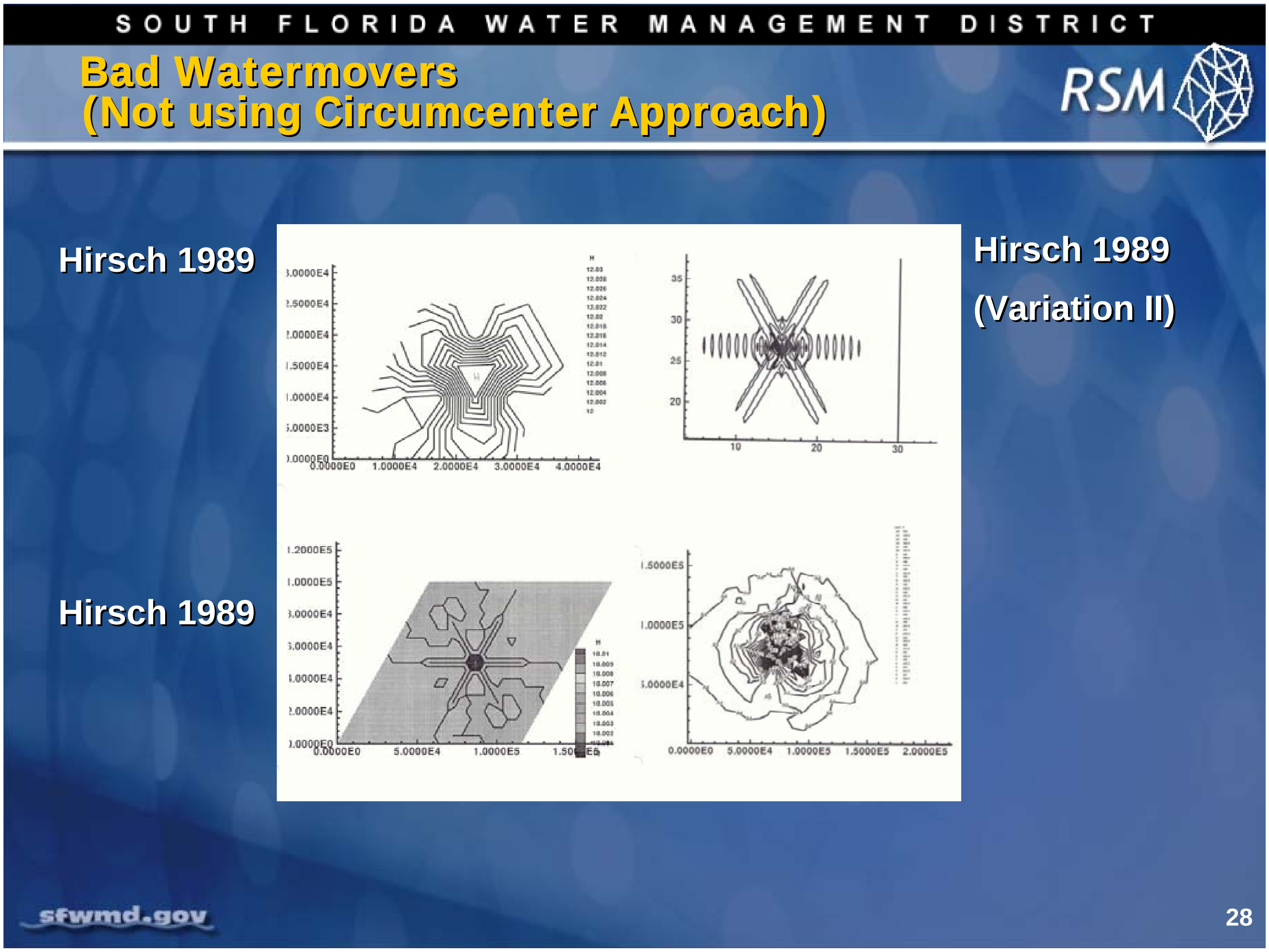
The value of T_r can be used to represent Darcy flow for groundwater. There are several possible formulations. The approach used in MODFLOW has been implemented in the RSM.



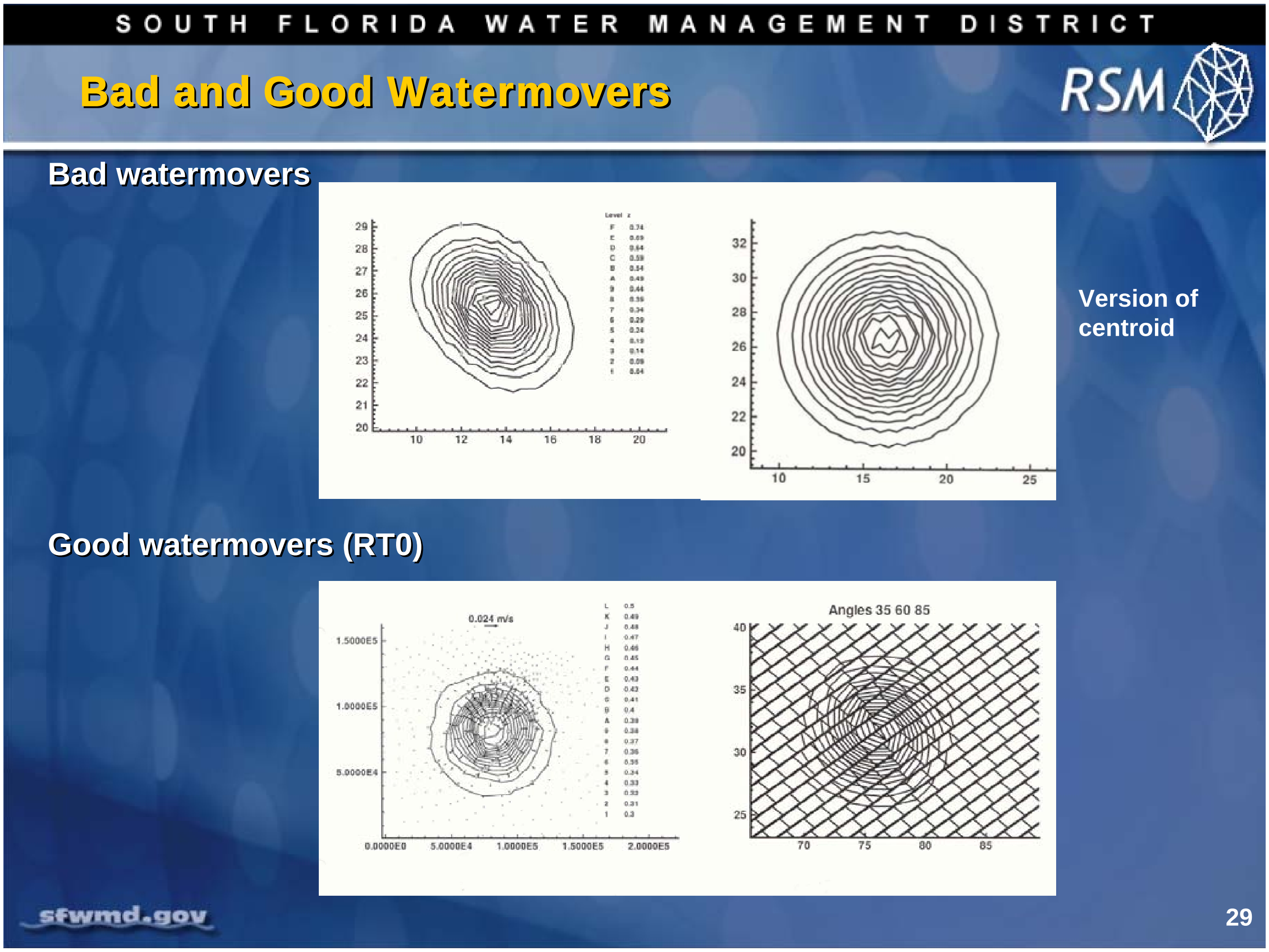
An important component of the solution method has been the implementation of lowest-order RT0 elements that solve the flow equations at the circumcenters. The use of circumcenters for determining the appropriate distance over which the DH is applied in the linear watermovers has made it possible to calculate accurate flows for irregular triangular meshes.



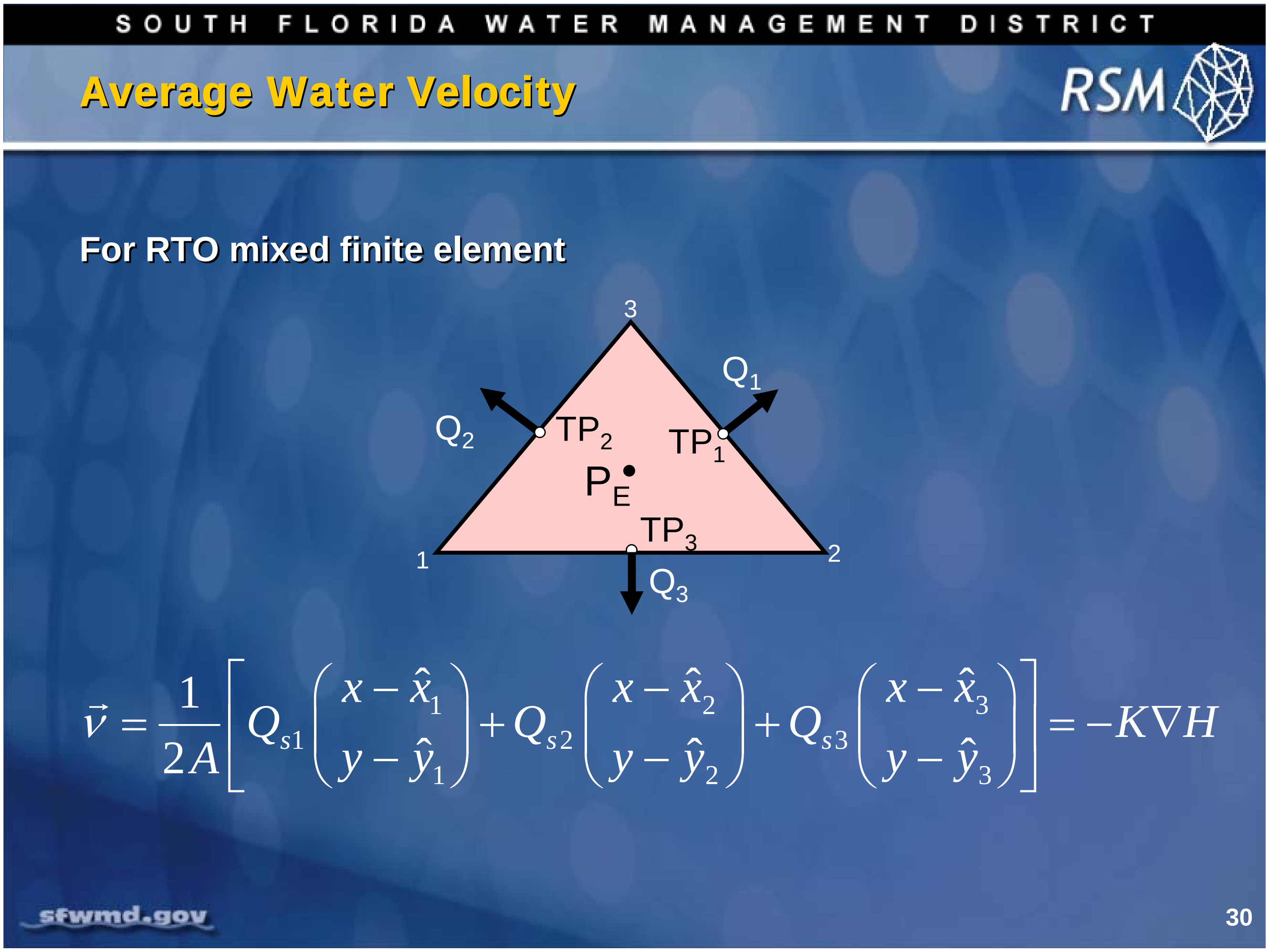
The circumcenter approach works well for acute triangles. It defaults to the Standard Finite Difference method for right triangles where Dd goes to zero between cells. The method is inaccurate for oblique cells, and these cells should be avoided in the mesh. Where they exist, the centroid is used instead of the circumcenter. This will result in a loss in accuracy in the results.



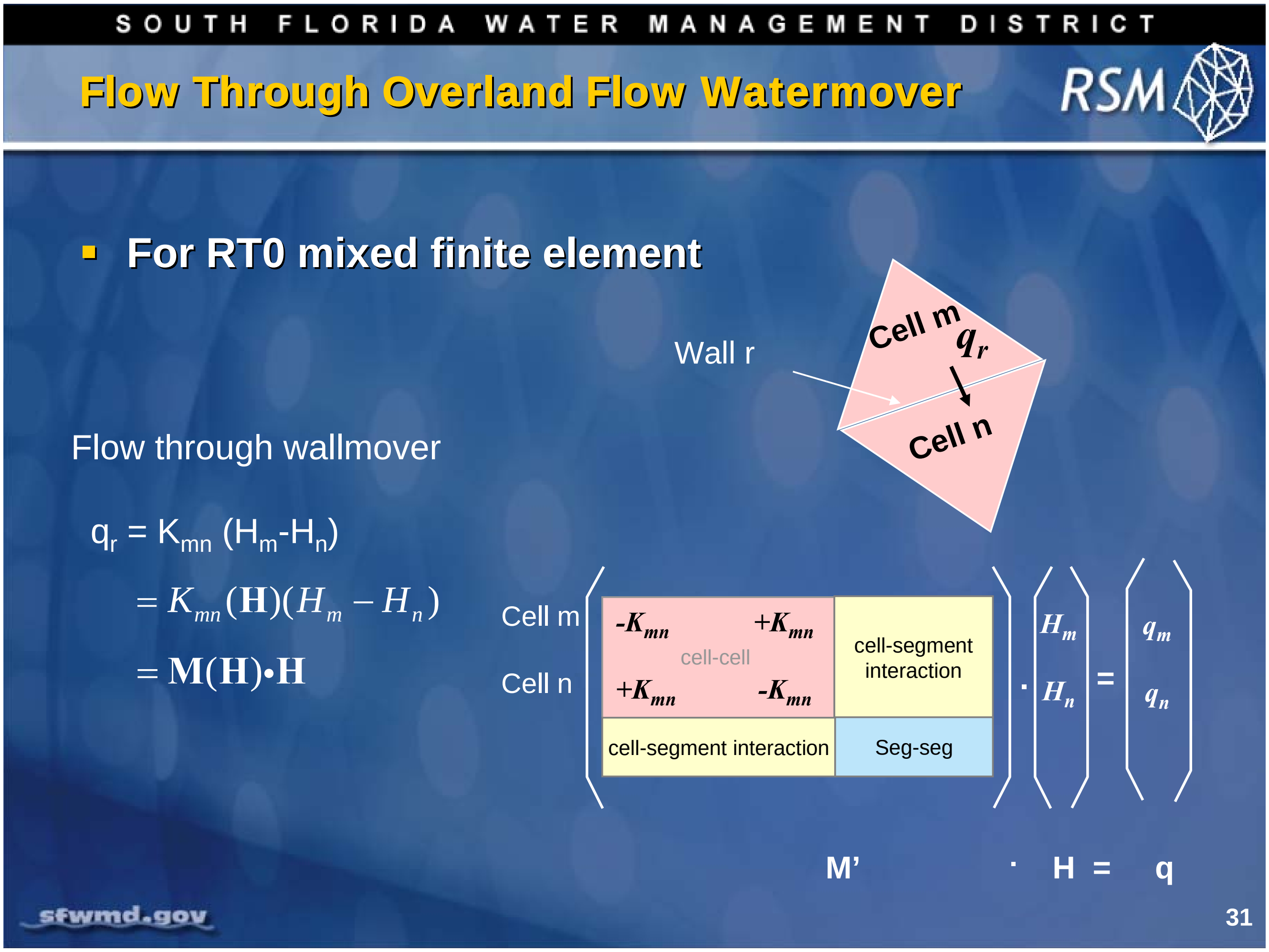
The use of circumcenters in the numerical solutions is critical for obtaining accurate results. Here are three examples of numerical solutions with errors from models that did not use circumcenters. Clearly, the numerical solutions were not correct.



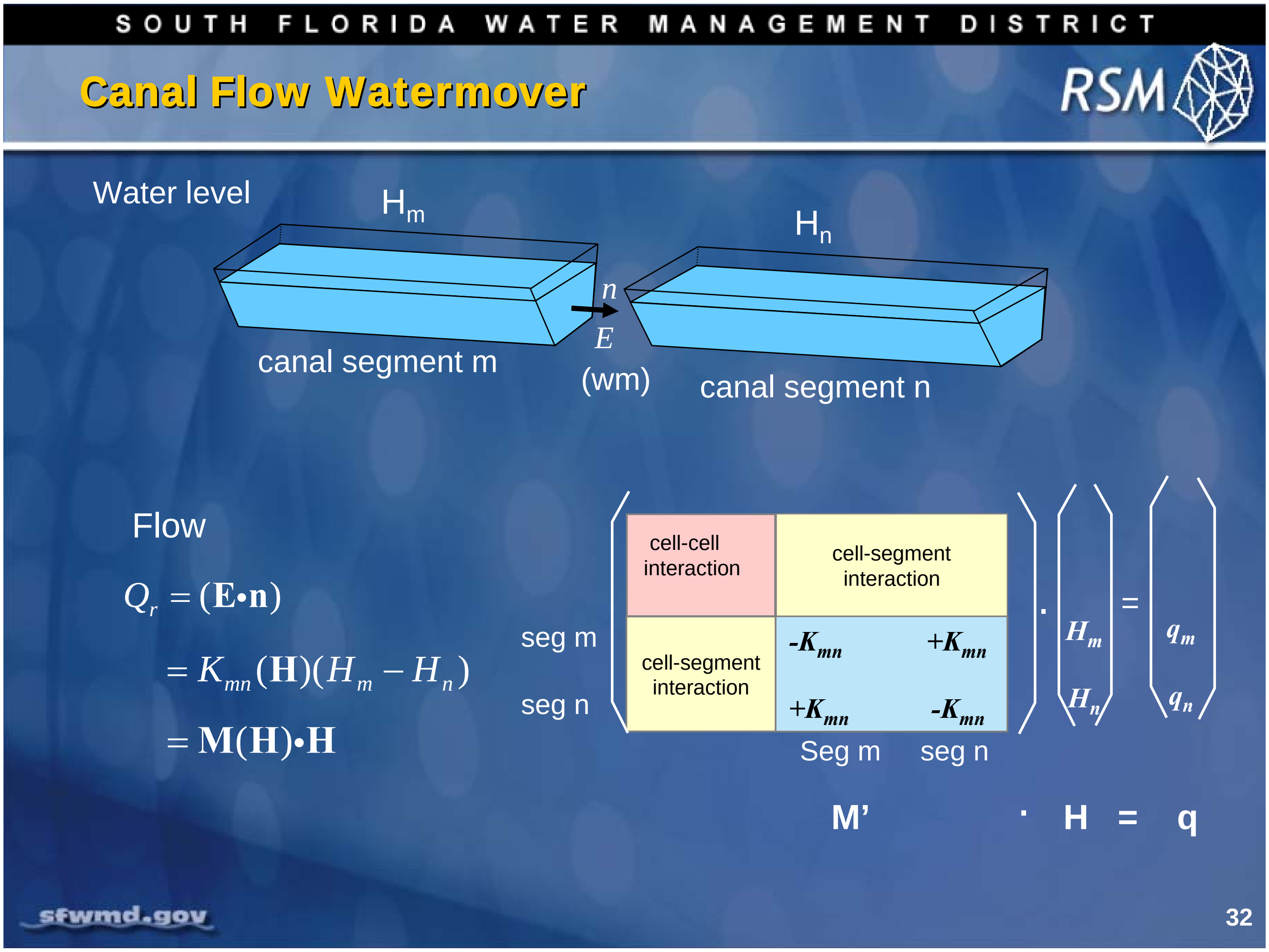
Here is a direct comparison of the same numerical model using either centroids or circumcenters in the numerical solution. The graphics show the head contours for an input of water at the center of the mesh made of acute triangles. The Bad watermovers graphics (above) show the distortion of the flow pattern due to the orientation of the triangles, and long times and short times. The Good watermovers graphics show the improved head patterns using RT0 (lowest order Raviart-Thomas) elements.



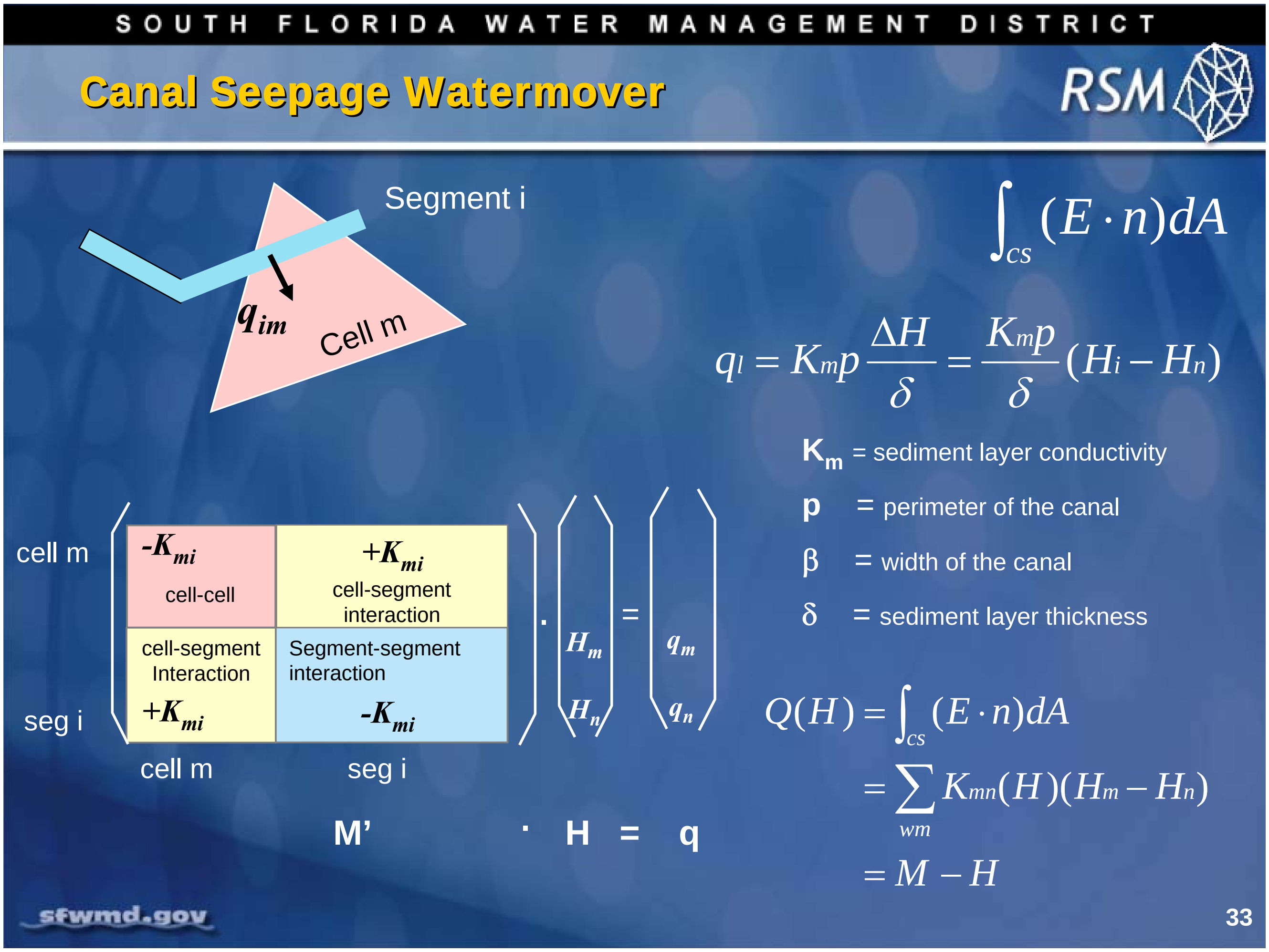
Another benefit to using RT0 finite elements is the capability to calculate the average velocity vector for each cell in the mesh where Q_{si} are the three edge fluxes, the coordinates of the center, and the coordinates of the center of the edges.



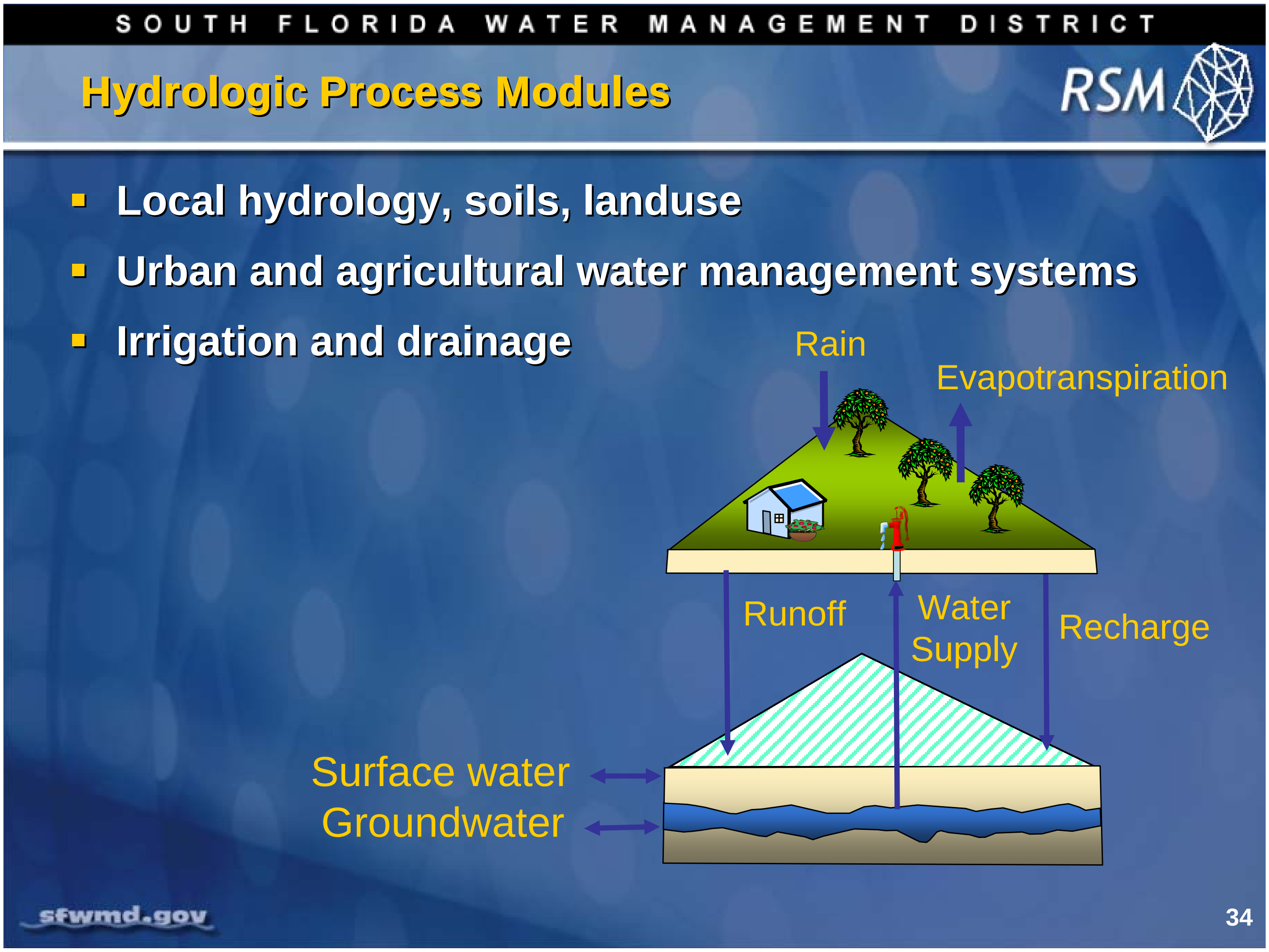
Cell watermovers are implemented as a set of paired water flow equations; one for Cell m and one for Cell n. These become part of the resistance matrix for those two cells. These will be combined with the flow equations for the other two adjacent cells.



For the watermovers for segments m and n, the resistance terms and the known flows are entered into the implicit solution matrix and flow vector.

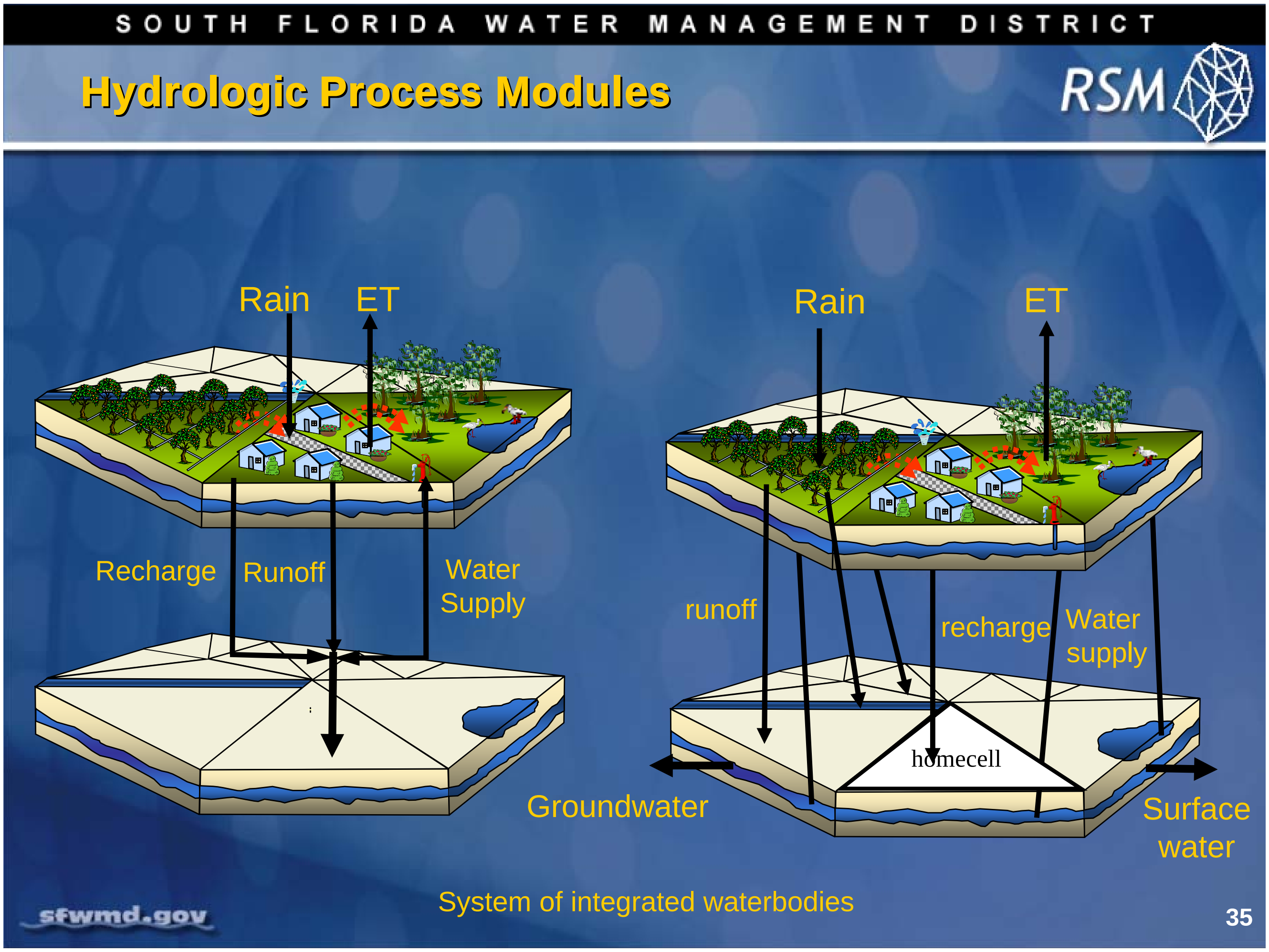


Where a segment crosses a cell there are cell-segment interaction terms in the resistance matrix. These interaction terms also exist for the cell-lake, cell-impoundment and other waterbodies and watermovers. There are Manning and Darcy-type watermovers for surface water/groundwater flow resistances for those interactions.

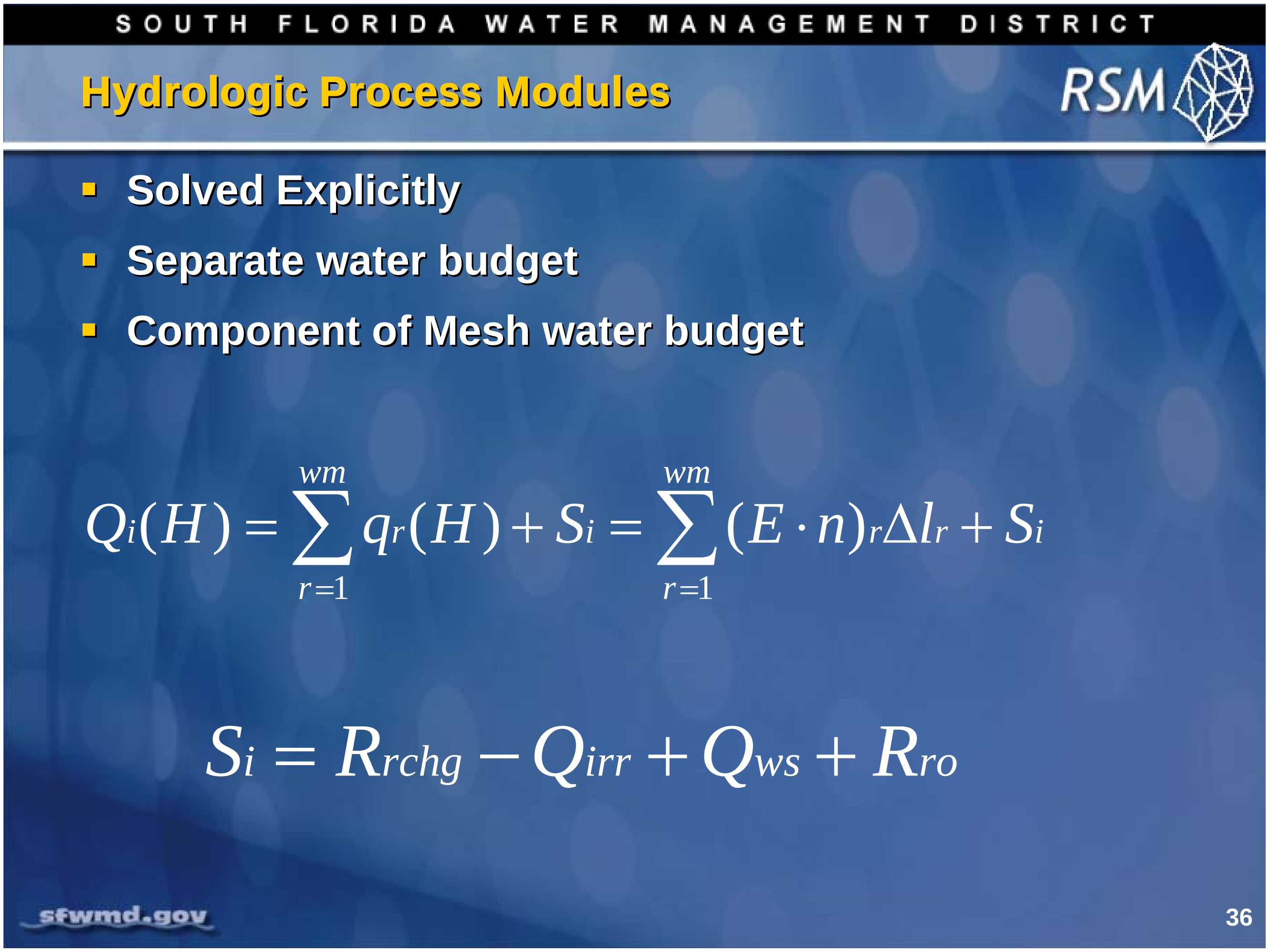


The Hydrologic Process Modules (HPMs) are designed to provide the interface between the detailed surface hydrology and the two-dimensional flow in the underlying mesh. The HPM provides the upper boundary condition to the mesh. The hydrology of the HPMs is calculated explicitly and the solution is applied to the mesh cells as known head-independent flows.

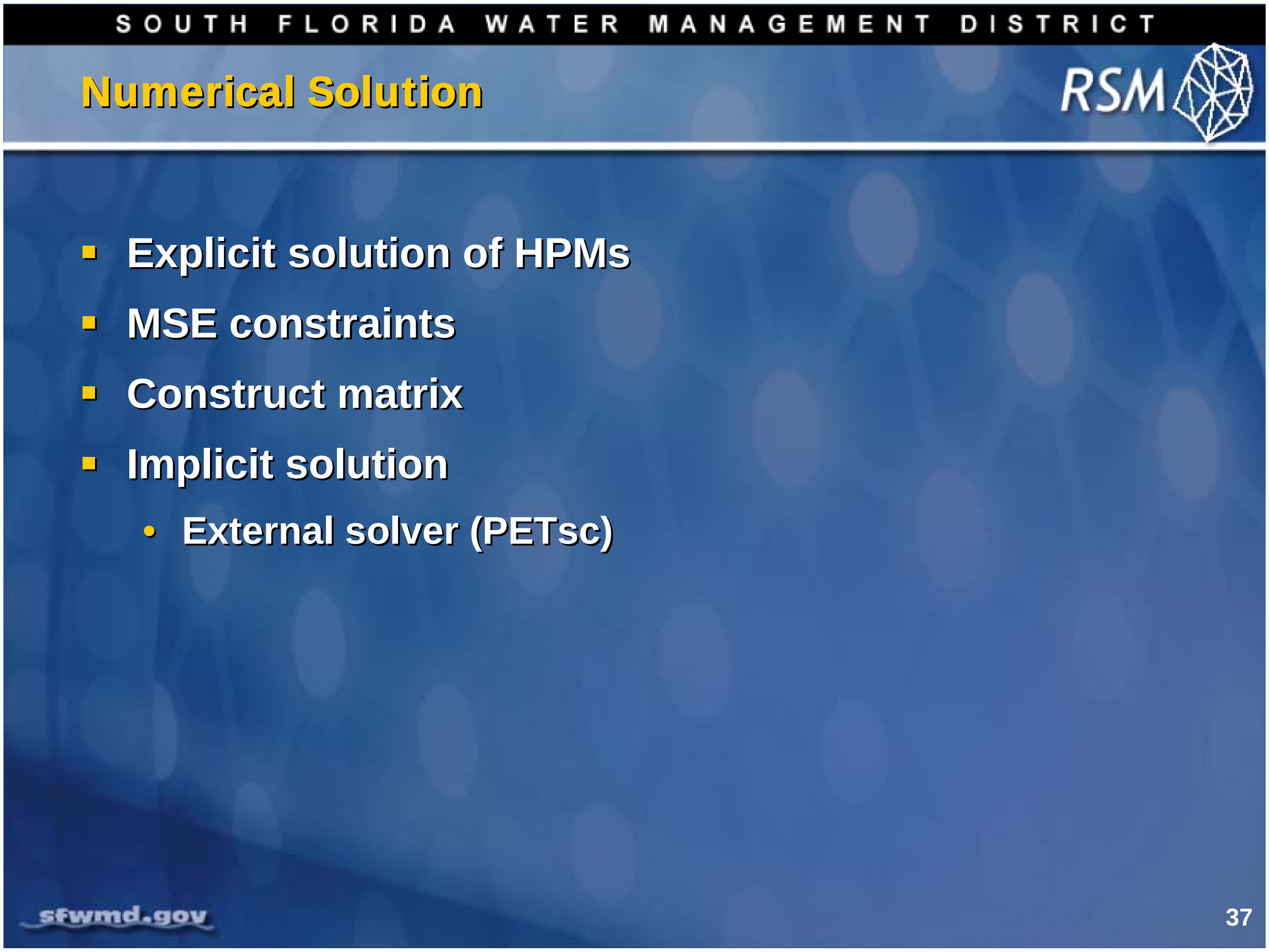
The hydrology of the HPMs may be a simple rain-ET process or include vertical processes, such as infiltration and percolation; as well as landscape processes such as irrigation, detention and urban water supply. The HPMs connect to waterbodies, most commonly to the underlying cells, through runoff, recharge and water supply.



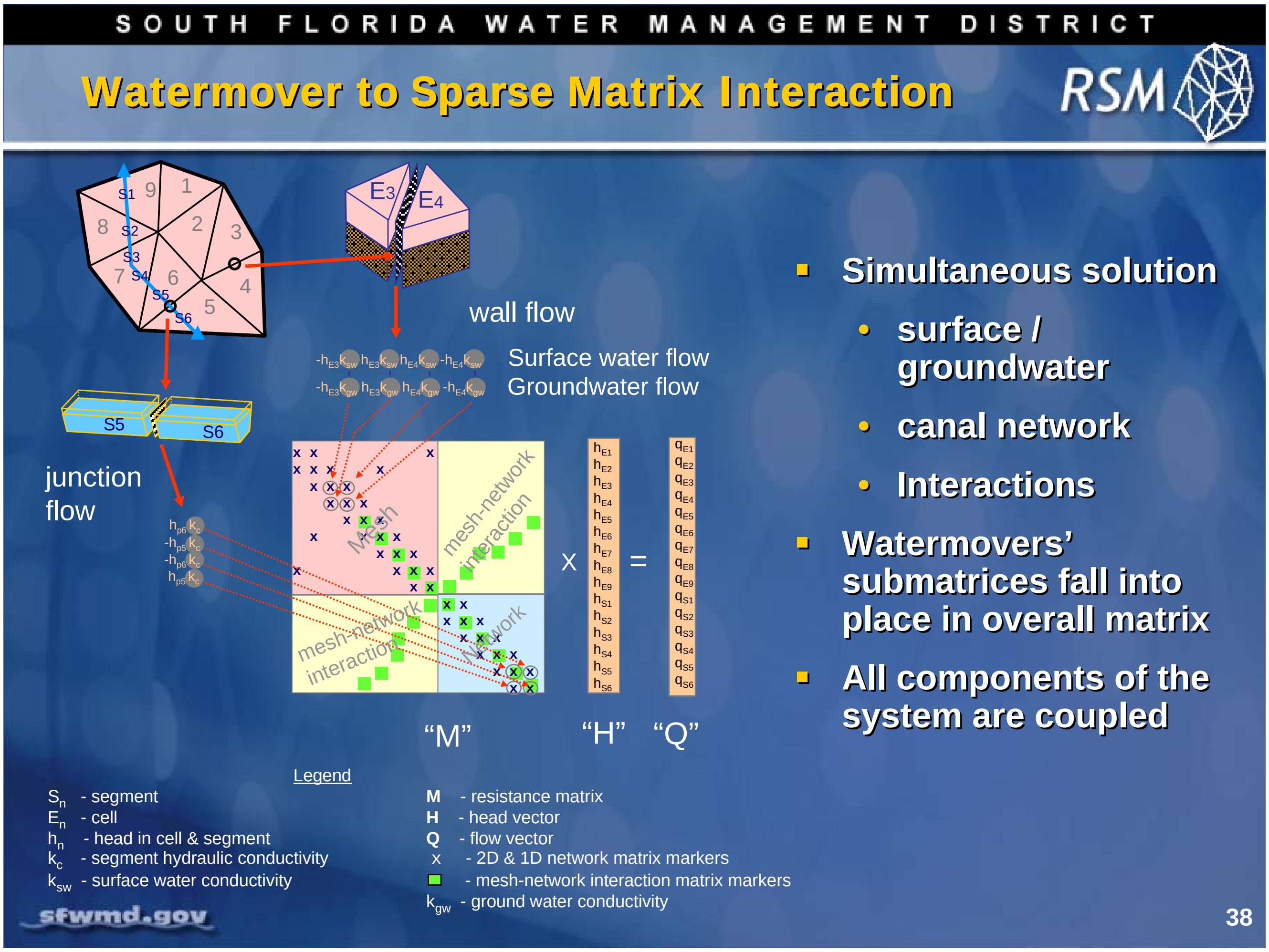
The HPMs provide the mechanism for modeling the local hydrology when the mesh cells are large and the landscapes are complex. Although the native landscapes consist of large areas of hydrologically similar landscapes, the developed urban and agricultural land contains local water management systems for irrigation, drainage and consumptive use. In a simple landscape the HPM interacts with the underlying "homecell" in complex landscapes. Runoff and water supply stresses may be directed to other waterbodies including lakes, segments and impoundments. The HPM allows for simulating this complexity without affecting the underlying 2D regional flow model.



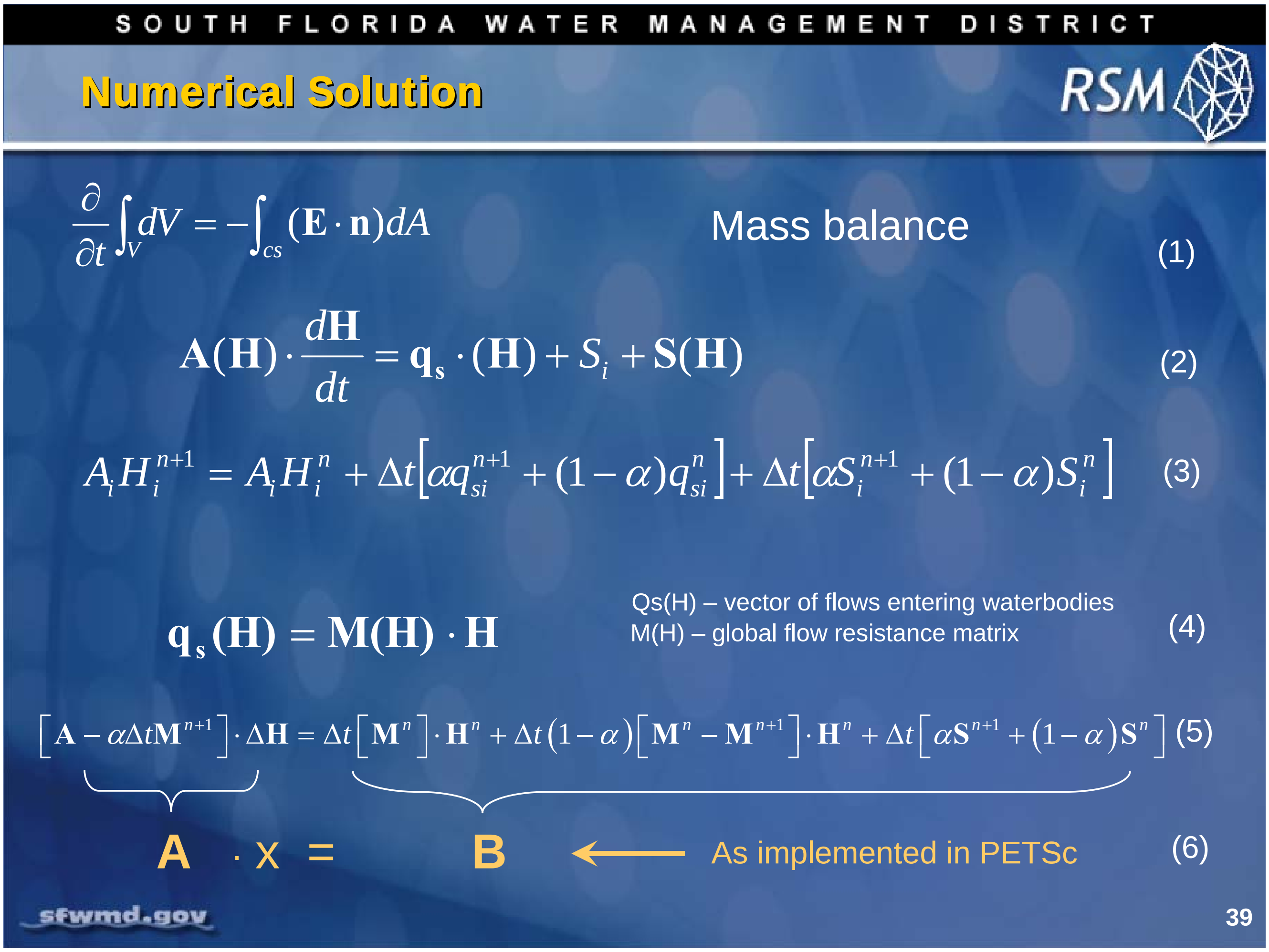
The HPMs maintain a separate water balance. The local hydrologic processes are solved explicitly at the beginning of each timestep and the results are applied to the waterbodies as one of the three components: recharge, runoff or water supply. These stressors, flows and demands that are applied to the waterbodies from the HPMs, appear as head-independent components of the flows Si for each waterbody. Essentially they behave as boundary condition flows calculated at each timestep.



The numerical solution for the RSM consists of five activities. The primary activity of the RSM is the construction of the resistance matrix and the known flow vector. The solution of HPMs provides the upper boundary conditions for the flow vector and the MSE constraints similarly fix selected watermover flows in the flow vector. Once the matrix is constructed, the solution for the Dheads is found using a sparse matrix solver. An external solver, PETSc, has been selected for the RSM.



The overall solution to the RSM can be visualized by the development of a matrix that includes the watermovers for each waterbody. For example, each cell has watermovers for the adjacent cells with segments that traverse the cell. As such there will be 3 to 5 entries for that waterbody in the 'M' matrix. The boundary condition flows including the contribution from the HPMs are provided in the 'Q' vector. The 'Q' vector is also known as the 'known' flow vector. Each of the coupled flow equations for the sending and receiving waterbodies are entered into the matrix. The implicit solution of this sparse matrix provides the heads for domain. In a simple view, the majority of the code in the RSM is devoted to filling the matrix for the sparse solver.



The Conservation of Mass applied to the Reynold's Transport Theorem results in a mass balance applied to all waterbodies (1).

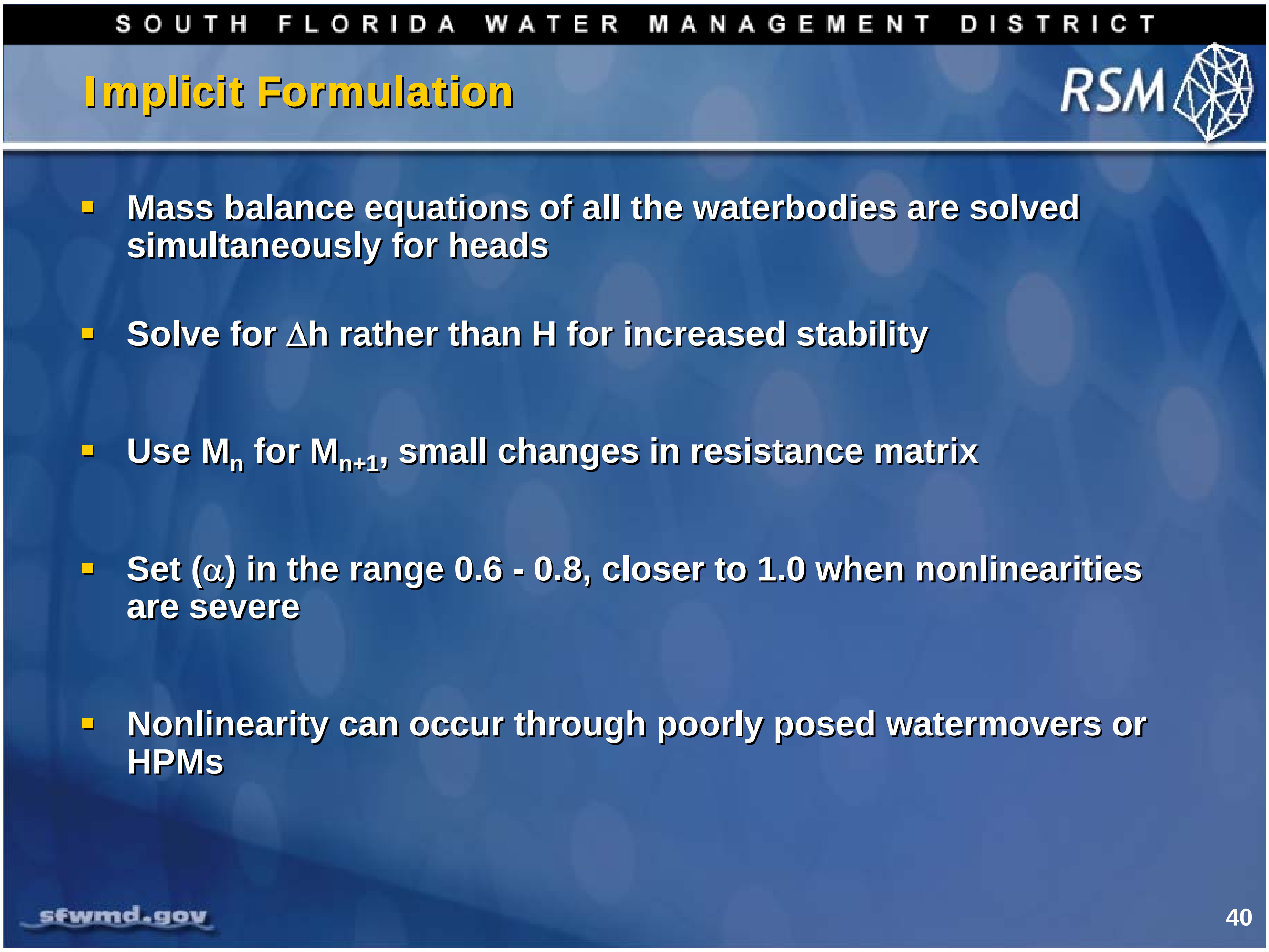
Applying the diffusion water solution to calculate the appropriate flows we obtain the appropriate ordinary differential equation that describes the change in head over time (2).

This can be solved as a finite difference problem in time for each waterbody *i* (3).

The overall solution of the heads for the waterbodies includes the resistance matrix, M, and the boundary condition flows Qs (4).

Equation (4) is solved using a partial implicit finite differencing scheme (5).

This equation (5) is solved by placing elements of (5) into the matrices (A, B) of the PETSc solver (6) and implementing the solver.



Some key concerns about running the RSM are listed here:

The head has been redefined in terms of DH rather than H.

The solution converges to the final answer more quickly when the values are small and where DH is zero (e.g. on dry days the model runs much faster).

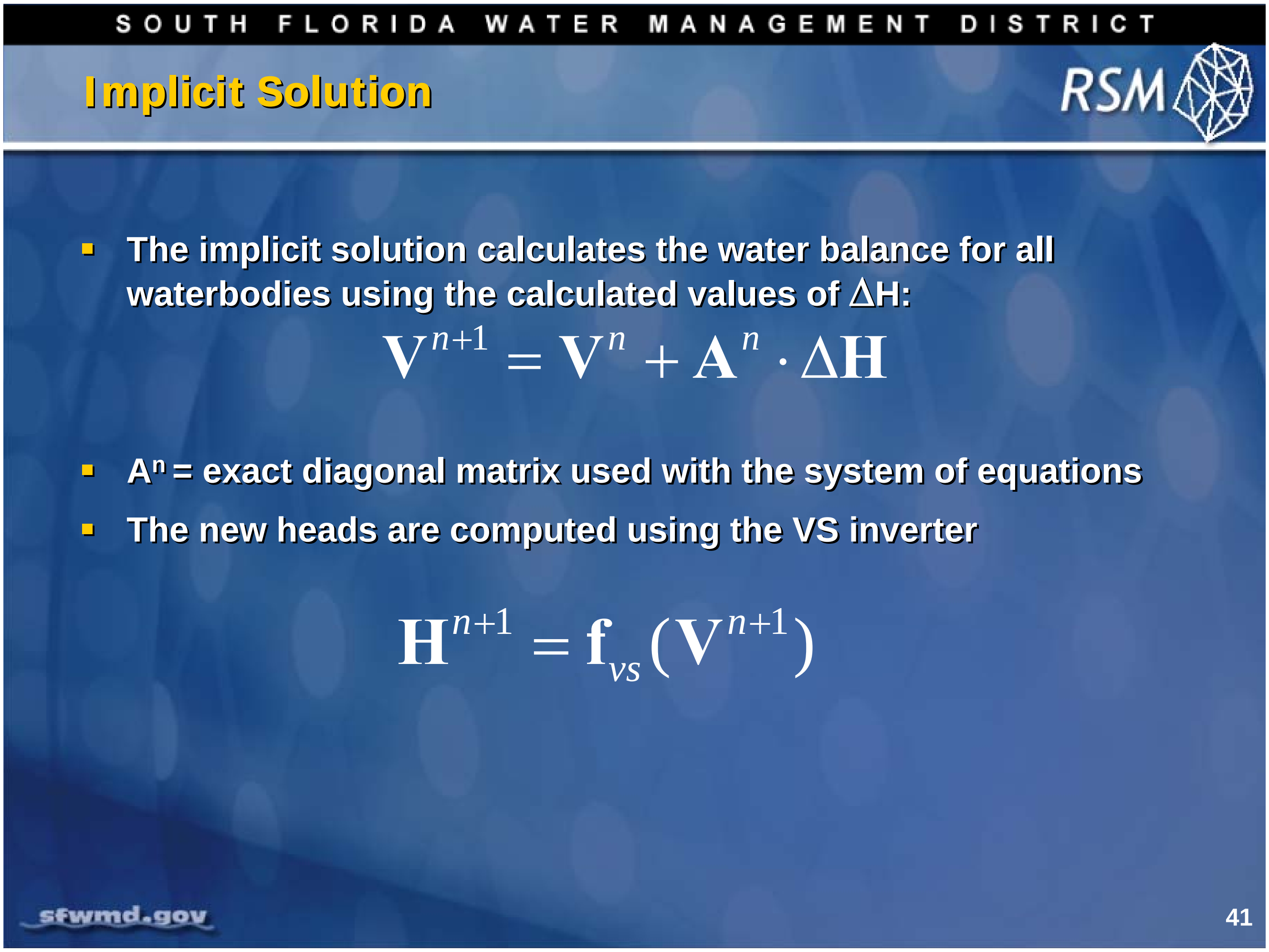
When there are small changes in the 'M' matrix, it is possible to use the previous version and thus increase the speed of execution.

The *a* value affects the degree of implicit solution.

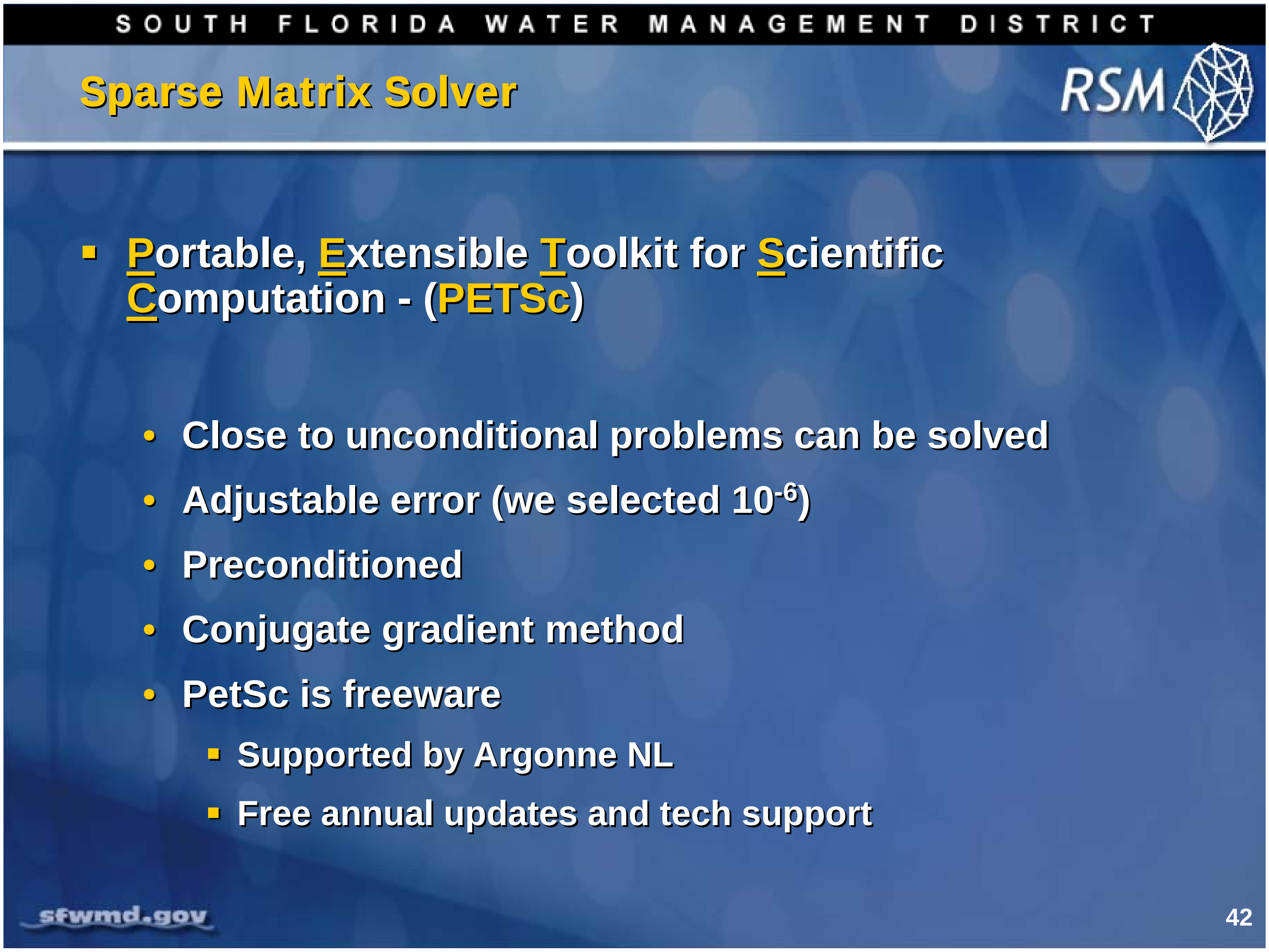
Values close to 1 increase the stability and convergence of the model but may reduce the accuracy of the answer.

The nonlinearity that occurs with some structures or poorly specified HPMs can create convergence problems in the implicit solution.

Frequently these problems are only identifiable from the model output.



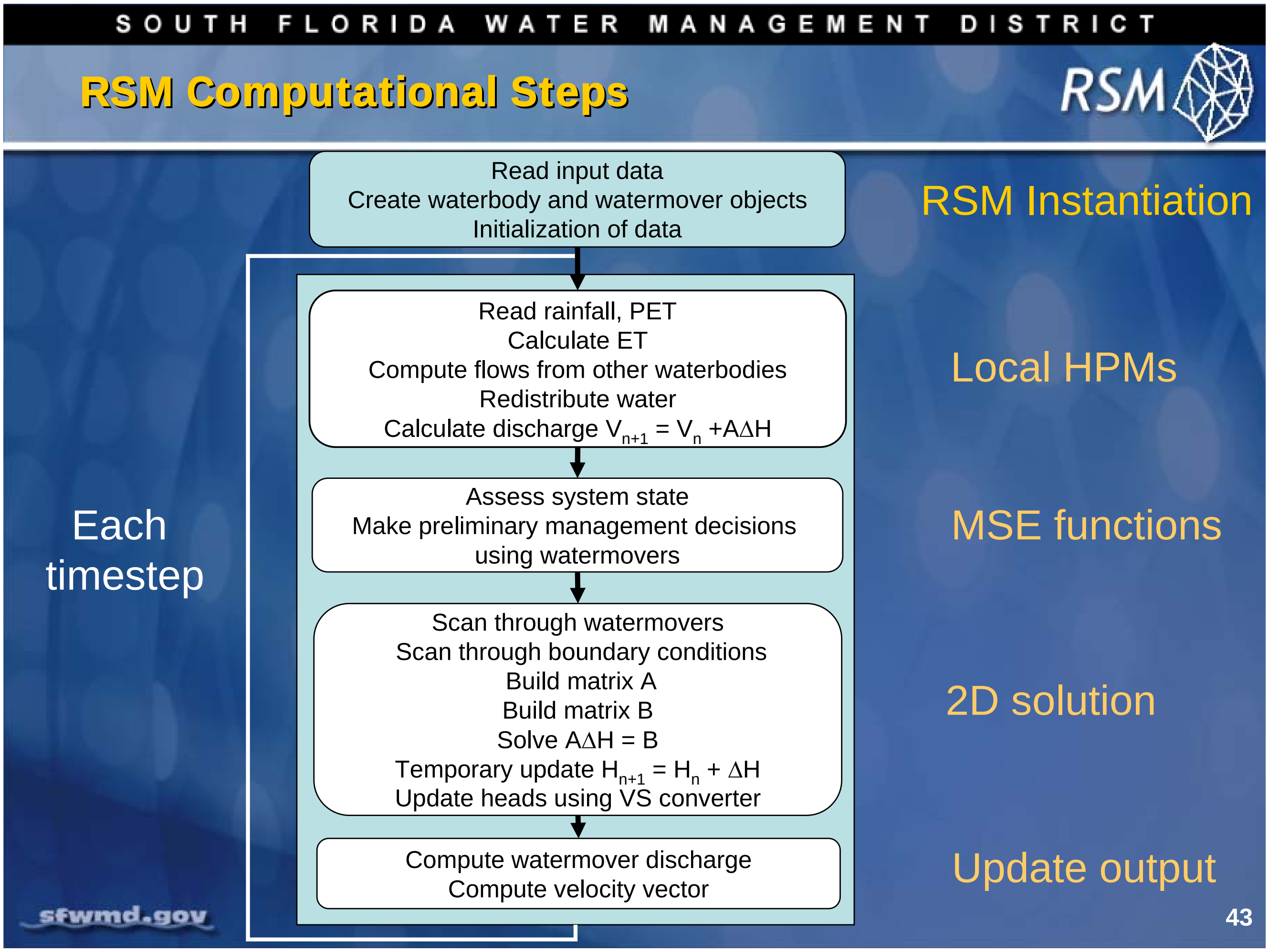
The implicit method takes into account the water balance in all waterbodies during the time interval between tn and t_{n+1}. Knowing the volume V at time tn and the new DH, it is possible to compute V_{n+1}. The new mass balance is calculated using V_{n+1}. The new heads are calculated using V_{n+1}. These are used in the model to compute the hydraulic driving force in the watermovers.



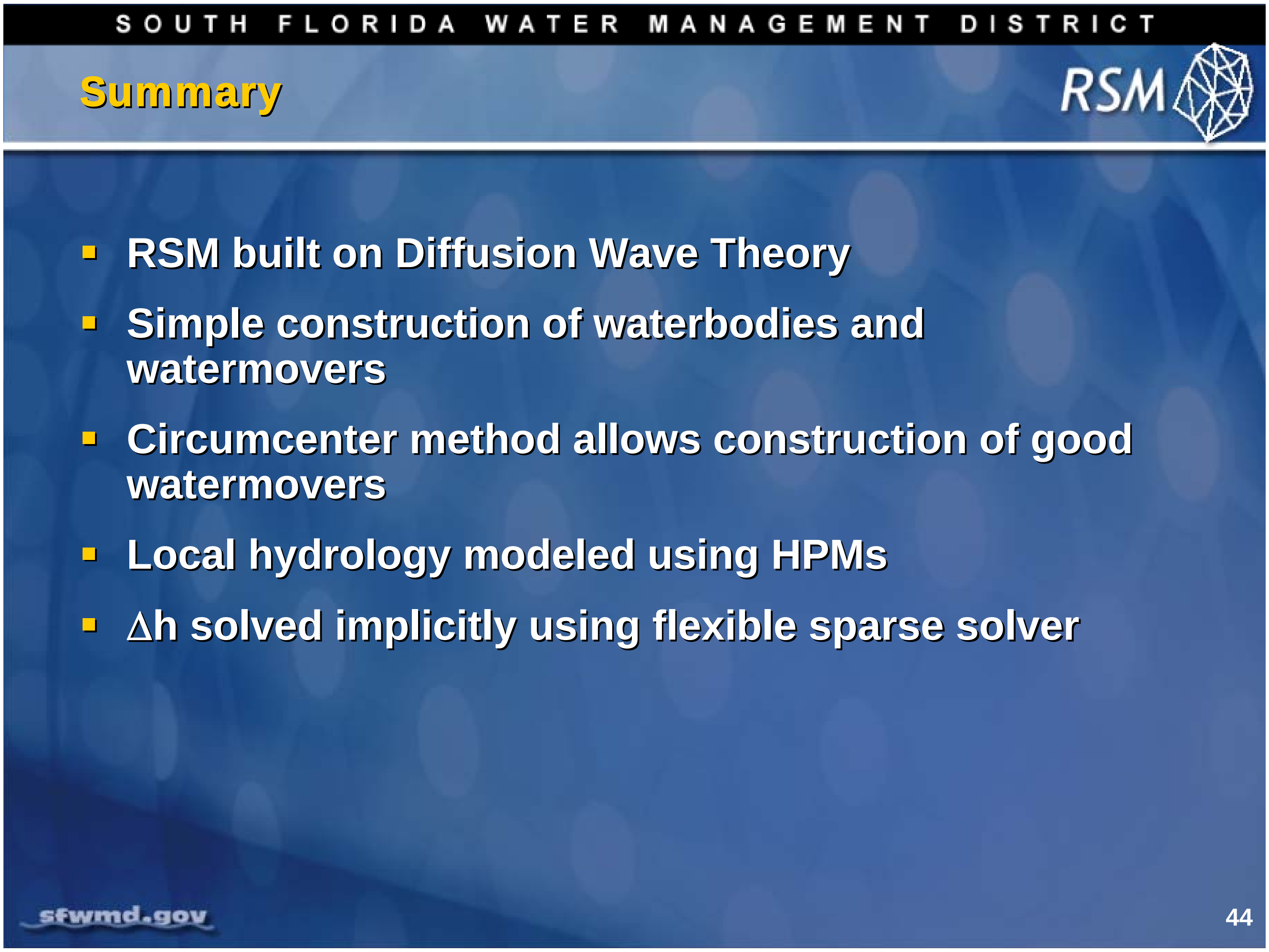
The PETSc sparse matrix solver is vital for the solution of the RSM matrix equation. This software package, created and maintained by Argonne National Laboratory, has several functions that allow for rapid solution of the matrix equations. In particular there are methods for pre-conditioning the matrix for a more rapid solution and there are several matrix solution methods from which to choose. The PETSc allows for selection of the appropriate convergence error; and, the method is highly stable.

(Refer to the http://www.mcs.anl.gov/petsc website for details.)

The PETSc is maintained and updated by Argonne, and the South Florida Water Management District's Hydrologic and Environmental Systems Modeling team is working with Argonne on enhancements for the solver, specifically for the RSM.



The computational approach for the RSM consists of a large loop for each timestep. At the start of a RSM run the XML input file is parsed and the waterbody and watermover objects are instantiated. For each time step, the HPMs are solved explicitly. The MSE uses the HPM results and boundary conditions to determine any flow constraints. The matrices for the implicit solver are loaded and PETSc provides the DH values for the solution. The solver may iterate until the solution converges. The results in terms of head, volume and velocity are output at the end of the timestep.


SOUTH FLORIDA WATER MANAGEMENT DISTRICT
Summary
RSM
RSM built on Diffusion Wave Theory
Simple construction of waterbodies and watermovers
Circumcenter method allows construction of good watermovers
Local hydrology modeled using HPMs
Δh solved implicitly using flexible sparse solver
sfwmd.gov
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Knowledge Assessment

1. What are the basic laws governing flow in RSM?
2. How is the Reynolds Transport Theorem implemented in RSM?
3. Why does the diffusion wave equation work well in south Florida?
4. What is an advantage of solving the flow equations in the integral form rather than the differential form?
5. What is the advantage of implementing the RSM in object-oriented code?
6. How many types of waterbodies and watermovers are in RSM?
7. What is the purpose of the SV and VS converters?
8. How does RSM solve the highly nonlinear flow equations?
9. How did RSM solve the problem of numerical error in 2D flow in the mesh?
10. How is the resistance matrix used to solve the flow equations?
11. How are the hydrologic process modules (HPMs) implemented in RSM?
12. What is the order of solution of processes in RSM?

Answers

1. The basic laws governing flow in RSM are the Reynolds Transport Theorem (RTT), conservation of mass and the diffusion flow flow equation.

2. The RTT is abstracted to form waterbodies and watermovers that move water between waterbodies.

3. Diffusion wave equation works well in low gradient landscapes where the flow is strongly controlled by bed resistance. It works well for flows up to a Froude number equal to 1.0.

4. In the integral form the equations can be solved for one variable, head.

5. In object-oriented code the waterbody objects are only implemented at runtime so the model is only as large as necessary and there are a large variety of waterbody types with different functionalities.

6. Currently, there are seven waterbody types and over 30 types of watermovers.

7. The SV and VS converters are necessary to convert between head (stage) and volume in each waterbody. The system of flow equations is solved for head while the conservation of mass is solved for volume.

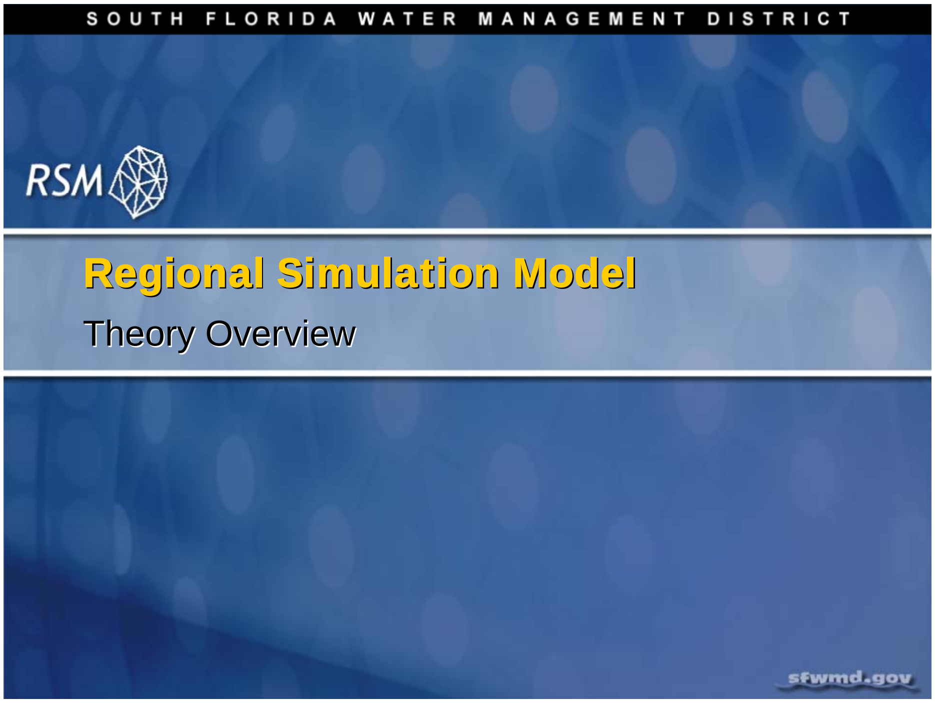
8. RSM solves the nonlinear flow by linearizing the watermovers as a function of head, solving the equations for Δhead rather than head and solving for small increments in Δhead.

9. Numerical errors in RSM were greatly reduced by implementation of the circumcenter method using RT0 elements. This was verified using numerical tests.

10. The resistance matrix, **M**, is a system of equations for each waterbody that includes the resistance terms for each of the watermovers attached to that waterbody. This is a key component of the **A** matrix solved by PETSc.

11. The HPMs, which simulate surface hydrologic processes, are solved explicitly and the resulting demands and flows are imposed on the 2D solution as boundary conditions.

12. The solution process for RSM follows this process:
    Update BCs → explicitly solve HPMs → solve MSE → 2D implicit solution→update heads.



Lab 2: Explore RSM Benchmarks

Time Estimate: 4 hours

Training Objective: To gain experience and develop skills running the Regional Simulation Model.

In this hands-on session, you are guided through six benchmarks that illustrate different features of the Regional Simulation Model (RSM). Running the benchmarks, changing various model parameters and observing each result, is the most effective way to develop proficiency and gain experience with the RSM.

NOTES:

For ease of navigation, you may wish to set an environment variable to the directory where you install the RSM code using the syntax

`setenv RSM /nw/oomdata_ws/nw/oom/sfrsm/workdirs/<username>/trunk`

Once you set the RSM environment variable to your trunk path, you can use $RSM in any path statement, such as:

`cd $RSM/benchmarks`

Training files are currently located in the following directories:

```
INTERNAL_TRAINING
|
|____data
|          |__geographic
|          |__C111
|          |__rain+et
|          |__glades-lecsa
|          |__losa_eaa
|          |__BBCW
|
|____trunk
|          |___benchmarks
|          |___hpmbud
|
|____labs
```

Files for this lab are located in the **`labs/lab2_BM2`** directory. Additional materials in the directory include:

```
mesh.ppt
hsetheorymanual.pdf
```

Additional files can be found in other lab directories, including:

`labs/lab1_BM1`: Flaig, E.G., R. Van Zee, and W. Lal. (2005) *Hydrologic process modules of the regional simulation model: An overview*.

`labs/lab4_complete_RSM`: HSE User Manual

`labs/lab11_hpm`: Smajstrla, A.G. (1990). *Agricultural Field Scale Irrigation Requirements Simulation (AFSIRS) Model.* Technical Manual Version 5.5. Agricultural Engineering Dept., University of Florida.

Activity 2.1: Investigate RSM Benchmarks

Overview

Activity 2.1 demonstrates the characteristics of six benchmarks used in the Regional Simulation Model. This activity includes six exercises:

- **Exercise 2.1.1** Run Benchmark 33r (RAMCC)
- **Exercise 2.1.2** Run Benchmark 37 (SVconverter)
- **Exercise 2.1.3** Run Benchmark 54 (HPM hubs)
- **Exercise 2.1.4** Run Benchmark 65 (Water Control District)
- **Exercise 2.1.5** Run Benchmark 66 (levee seepage)
- **Exercise 2.1.6** Run Benchmark 71 (Impoundments)

As you progress through each exercise, you will gain experience as well as an understanding of the model's functionality.

Exercise 2.1.1 Benchmark 33r (RAMCC)

Benchmark 33r was designed to test the behavior of the RAMCC HPM which is designed to simulate the hydrology of irrigated agricultural land. The documentation for the RAMCC model is provided with the *Regional Simulation Model (RSM) Hydrologic Simulation Engine (HSE) User Manual* available online:

https://my.sfwmd.gov/pls/portal/docs/PAGE/PG_GRP_SFWMD_HESM/PORTLET_RSM/TAB1346042/HSE_USERMAN.PDF

Additionally, there is a design document that describes how RAMCC works and a manual for the Agricultural Field Scale Irrigation Requirement Simulation Model (AFSIRS Model) from which RAMCC was derived. The *AFSIRS Manual (mentioned on page 2.2)* describes the model parameters.

Several HPMs are used in BM33r and applied to different cells in the standard 18-cell benchmark mesh. We will observe the water budget differences that occur for the different crop types and the effect that changing the different crop parameters have on the water budget.

Table 2.1 HPMs applied to each cell in the Benchmark 33r mesh

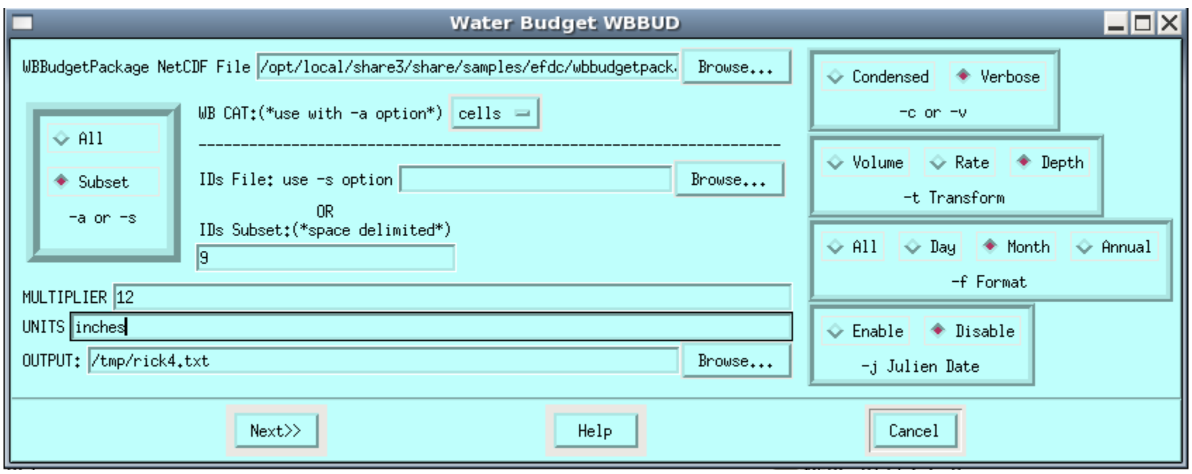
Cell	Hydrologic Process Module	
1	Ramcc:	Citrus-low volume
2	Ramcc:	Citrus-crown flood
3	Ramcc:	Sugar Cane
4	Ramcc:	Tomato-spring
5	Ramcc:	Tomato-fall
6	Ramcc:	Rice-seepage-spring
7	Ramcc:	Rice-seepage-fall
8	unsat:	Prairie
9	layer5:	Marsh
10	Ramcc:	Citrus-low volume
11	Ramcc:	Citrus-crown flood
12	Ramcc:	Sugar Cane
13	layer5:	Forest
14	unsat:	Prairie
15	layer5:	Forest
16	layer5:	Marsh
17	unsat:	Prairie
18	layer5:	Marsh

For Benchmark 33r (RAMCC), run **`wbbud`** from the RSM Graphical User Interface (RSM GUI). Then, from the command line, run **`hpmbud`** for cells 1-9 to see how the use of different crops impacts the model.

3. Run benchmark 33R
   - **`cd $RSM/benchmarks/BM33r`**
4. Edit **`run3x3.xml`**
   - Add **`<wbbudgetpackage file=”wbbudget.nc” />`** to **`<output>`** block
5. Use the RSM GUI to rerun **`BM33r/run3x3.xml`**
6. Run water budgets; **`wbbud`** is accessible under the Process Model Output dropdown menu

Use the following settings to run the report for this exercise:

File	**`./RSM/trunk/benchmarks/BM33r/wbbudget.nc`**
Select	**`Depth transform`** option
Select	**`Subset`** option
Enter	single value of **`9`** into the **`IDs subset`** input field
Enter	multiplier of **`12`** to convert feet to inches
Type	**`inches`** into the units input field
Select	**`Month`** format option
Enter	location and **`filename`** for the output file to be generated
Click	**`Next >>`** to generate the **`wbbud`** report



7. Run **hpmbud** from the command line using the following options:
   - **`$RSM/hpmbud/hpmbud –n hpmbudget_mo.nc –s cell1 –d –m 12`**

Unlike **`wbbud`**, you have to create a file with the cell values in it to run **`hpmbud`**. Look at the various components of the water budget. The file **`cell1`** contains the single value "1". Each file contains a list of cells and in this simple case each file has one value for a waterbudget on the hpm for one cell.

8. Repeat for **`–s cell2,3,4,5,6,7,8,9`**. Using the **`wbbud`** tool in the RSM GUI, enter a space delimited list of IDs (**`2 3 4 5 6 7 8 9`**). The tool can also be run using one input file containing a single-column list of waterbody IDs.

9. To easily compare annual values among the different crop types, edit the XML file and add the following element to the **run3x3.xml** file:
   - **<hpmbudgetpackage file=”hpmbudget_yr.nc”> dbintl=”525600” />**

The results of this exercise demonstrate the effect of different landcover types on the ET, seepage, runoff and water supply stresses that the HPMs impose on the cells. In this way a benchmark can be used to provide a simple testbed for gaining an understanding of the impact of a Hydrologic Simulation Engine (HSE) feature on the model output.

Next, modify the soil properties for the HPM **“citrus-micro drip”** and compare the results.

10. Run BM33r using the RSM GUI and output budget:
    - **$RSM/hpmbud/hpmbud –n hpmbudget_yr.nc –s cell1 –d –m 12**
11. Open **gedit** editor in a separate window
12. Open **ramcc.xml**
13. Edit **ramcc.xml**:
    - Locate **<entry id=”4” label=”citrus – micro drip”>**
    - Locate **<afsoil … >**
    - Change **minwc** from **0.07** to **0.20**
14. Run RSM
15. Run **hpmbud** again for **Cell 1**:
    - **$RSM/hpmbud/hpmbud –n**

This method can be used to perform simple sensitivity analysis to increase your understanding of the model.

The listing for the main XML file, **run3x3.xml**, for BM33r is provided in Fig. 2.1. The listing for the **ramcc.xml** HPM file is provided in Fig. 2.2. The content of the XML files is explained in the HSE User Manual, available online at:

https://my.sfwmd.gov/pls/portal/docs/PAGE/PG_GRP_SFWMD_HESM/PORTLET_RSM/TAB1346042/HSE_USERMAN.PDF

```
<?xml version="1.0" ?>
<!DOCTYPE hse SYSTEM "../hse.dtd" [
<!ENTITY ramccdata SYSTEM "ramcc.xml">
]>
<hse>
  <control  tslen="24"              tstype="hour"
            startdate="01jan1965"  starttime="0000"
            enddate="31dec1966"    endtime="2400"
            alpha="0.900"          solver="PETSC"     method="gmres"
            units="english"        precond="ilu">
  </control>
  <mesh>
     <geometry file="mesh3x3.2dm"> </geometry>
     <mesh_bc>
        <noflow  section="ol_gw">  <nodelist> 5 6 7 8 </nodelist></noflow>
        <noflow  section="ol_gw">  <nodelist> 9 10 11 12 </nodelist></noflow>
     <wallghb  value="0.10" label="general head 1">
        <nodelist>  4 8 12 16 </nodelist>
        <uniform>  <const value="499"></const> </uniform>
     </wallghb>
     <wallghb  value="0.10" label="general head 1">
       <nodelist>  1 5 9 13 </nodelist>
       <uniform>  <const value="499"></const> </uniform>   </wallghb>
     </mesh_bc>
     <shead><gms file="hin3x3.dat"></gms></shead>
     <rain>
        <dss file="weather.dss" pn="/LOSA/AREAL/RAINFALL//1DAY/ESTIMATED/"
             mult="0.0833" units="INCHES">   </dss>
     </rain>
     <refet>
        <dss file="weather.dss" pn="/LOSA/AREAL/REFET//1DAY/ESTIMATED/"
             mult="0.0833" units="INCHES">   </dss>
     </refet>
     <bottom>  <const value="400.0">   </const> </bottom>
     <surface> <const value="501.0"> </const> </surface>
     &ramccdata;
     <conveyance> <mannings a="0.0500" detent="0.00001"></mannings>
     </conveyance>
     <transmissivity> <unconfined k = "0.002"> </unconfined>  </transmissivity>
     <svconverter>  <constsv sc="0.2"> </constsv>  </svconverter>
  </mesh>

  <output>
     <budgetpackage file="budget_mo.nc" dbintl="43200"/>
     <hpmbudgetpackage file="hpmBudget_mo.nc" dbintl="43200"/>
     <cellmonitor id="1" attr="head" label="c1"><dss file="heads"/>
     </cellmonitor>
```

Figure 2.1 A portion of **`run3x3.xml`** main XML input file for Benchmark 33r

```
<!-- Cell heads -->
    <cellmonitor id="1" attr="head">  <dss file="head1.dss"
                       pn="/c1/citrus/head//1day/micro/"></dss>  </cellmonitor>
    <cellmonitor id="3" attr="head">  <dss file="head1.dss"
                      pn="/c3/sugarcane/head//1day/sub/"></dss>  </cellmonitor>
    <cellmonitor id="4" attr="head">  <dss file="head1.dss"
                    pn="/c4/Tomato/head//1day/micro-sp/"></dss>  </cellmonitor>
    <cellmonitor id="5" attr="head">  <dss file="head1.dss"
                    pn="/c5/Tomato/head//1day/micro-fl/"></dss>  </cellmonitor>
    <cellmonitor id="6" attr="head">  <dss file="head1.dss"
                     pn="/c6/rice/head//1day/flood spr/"></dss>  </cellmonitor>
    <cellmonitor id="6" attr="head">  <dss file="head1.dss"
                     pn="/c6/rice/head//1day/flood spr/"></dss>  </cellmonitor>
    <cellmonitor id="7" attr="head">  <dss file="head1.dss"
                    pn="/c7/rice/head//1day/flood fall/"></dss>  </cellmonitor>
    <cellmonitor id="16" attr="head">  <dss file="head1.dss"
                  pn="/c16/layer5/head//1day/micro irr/"></dss>  </cellmonitor>
    <cellmonitor id="18" attr="head">  <dss file="head1.dss"
                  pn="/c18/layer5/head//1day/micro irr/"></dss>  </cellmonitor>
    <cellmonitor id="11" attr="head">  <dss file="head1.dss"
                   pn="/c11/Citrus/head//1day/Crown Fd/"></dss>  </cellmonitor>
<!--                                     -->
<!-- Citrus Micro                        -->
    <hpmmonitor id="1" attr="hpm_watercontent">  <dss file="output1.dss"
                       pn="/c1/citrus/swc//1day/micro/"></dss>  </hpmmonitor>
    <hpmmonitor id="1" attr="hpm_wsupply">  <dss file="output1.dss"
                   pn="/c1/citrus/wsupply//1day/micro/"></dss>  </hpmmonitor>
    <hpmmonitor id="1" attr="hpm_runoff">  <dss file="output1.dss"
                    pn="/c1/citrus/runoff//1day/micro/"></dss>  </hpmmonitor>
    <hpmmonitor id="1" attr="hpm_et">  <dss file="output2.dss"
                        pn="/c1/citrus/et//1day/micro/"></dss>  </hpmmonitor>
.
.
.
    <wbbudgetpackage file="wbbudget.nc" />
    <budget file="budget.out"></budget>
  </output>
</hse>
```

Figure 2.1 **`run3x3.xml`** main XML input file for Benchmark 33r (continued)

```
<hpModules>
  <indexed file="lu.index">
    <hpmEntry id="1">
      <unsat ew="0.2" kw="1.0" rd="0.5" xthresh="0.02"
             pthresh="0.10" pd="3.0" kveg="0.75"></unsat> </hpmEntry>
    <hpmEntry id="2">
      <layer5 ew="0.2" kw="1.0" rd="2.0" xd="3.0" pd="3.0" kveg="0.5">
      </layer5> </hpmEntry>
    <hpmEntry id="3">
      <layer5 ew="0.2" kw="1.0" rd="0.0" xd="0.5" pd="3.0" kveg="0.65">
      </layer5> </hpmEntry>

    <hpmEntry id="4" label="citrus - micro drip">
      <ramcc>
        <afcrop label="citrus" id="4" j1="01-01" jn="12-31"
                depth1="0.762" depth2="1.524">
          <kctbl>
            0.90 0.90 0.90 0.90 0.95 1.00
            1.00 1.00 1.00 1.00 1.00 1.00
          </kctbl>
          <awdtbl>
            0.67 0.67 0.33 0.33 0.33 0.33
            0.67 0.67 0.67 0.67 0.67 0.67
          </awdtbl>
        </afcrop>
        <afirr  wtd="1.0">
          <irrmeth label="MICRO, DRIP" id="2" eff=".85"
                   arzi="0.5" exir="0.4"></irrmeth>
          <irrmgmt label="DEFICIT" trigcode="0" value="100"></irrmgmt>
        </afirr>
        <!-- wc was originally 0.07 -->
        <afsoil label="0.8  SOILS" depth="2.4384" minwc=".07" maxwc=".09"
                cond="1"></afsoil>
      </ramcc> </hpmEntry>

    <hpmEntry id="5" label="citrus - crown flood">
      <ramcc>
        <afcrop label="citrus" id="4" j1="01-01" jn="12-31"
                depth1="0.762" depth2="1.524">
          <kctbl>
            0.90 0.90 0.90 0.90 0.95 1.00
            1.00 1.00 1.00 1.00 1.00 1.00
          </kctbl>
          <awdtbl>
            0.67 0.67 0.33 0.33 0.33 0.33
            0.67 0.67 0.67 0.67 0.67 0.67
          </awdtbl>
        </afcrop>
        <afirr label="CROWN FLOOD" wtd="1.4">
          <irrmeth id="8" eff="0.95" arzi="1.0" exir="0.5"
                   crown="0.4572"></irrmeth>
          <irrmgmt trigcode="0"></irrmgmt>
        </afirr>
        <afsoil label="0.8  SOILS" depth="6.0" minwc=".20" maxwc=".20"
                cond="1"> </afsoil>
      </ramcc> </hpmEntry>
```

Figure 2.2 **`ramcc.xml`** XML for HPMs for Benchmark 33r

```
<hpmEntry id="6" label="sugar - subirrigation">
   <ramcc>
     <afcrop label="sugar" id="15" j1="01-01" jn="12-31"
             depth1="0.4572" depth2="0.9144">
       <kctbl>
         0.47 0.33 0.42 0.52 0.77 0.96
         0.71 0.66 0.68 0.50 0.52 0.55
       </kctbl>
       <awdtbl>
         0.65 0.65 0.35 0.35 0.35 0.50
         0.65 0.65 0.65 0.65 0.65 0.65
       </awdtbl>
     </afcrop>
     <afirr label="SEEPAGE, SUBIRRIGATION" wtd="1.0">
       <irrmeth id="7" eff="0.5" arzi="1.0" exir="1.0"></irrmeth>
       <irrmgmt trigcode="0"></irrmgmt>
     </afirr>
     <afsoil label="MUCK SOILS" depth="2.4384" minwc=".20" maxwc=".50"
             cond="1"> </afsoil>
   </ramcc> </hpmEntry>

 <hpmEntry id="7" label="tomato - micro irrigation">
   <ramcc>
     <afcrop label="tomato" id="60" j1="01-01" jn="04-30"
             depth1="0.2286" depth2="0.3048">
       <kctbl>
         1.05 0.75 0.22 0.30 0.30 0.18
       </kctbl>
       <awdtbl>
         0.40 0.40 0.40 0.65
       </awdtbl>
     </afcrop>
     <afirr label="MICRO, SPRAY" wtd="0.9144">
       <irrmeth id="3" eff="0.8" arzi="0.5" exir="0.4"></irrmeth>
       <irrmgmt trigcode="0"></irrmgmt>
     </afirr>
     <afsoil label="0.8  SOILS" depth="2.4384" minwc=".07" maxwc=".07"
             cond="1"> </afsoil>
   </ramcc> </hpmEntry>

 <hpmEntry id="8" label="fall tomato - micro irrigation">
   <ramcc>
     <afcrop label="tomato" id="60" j1="09-01" jn="12-31"
             depth1="0.2286" depth2="0.3048">
       <kctbl>
         1.05 0.75 0.22 0.30 0.30 0.18
       </kctbl>
       <awdtbl>
         0.40 0.40 0.40 0.65
       </awdtbl>
     </afcrop>
     <afirr label="MICRO, SPRAY" wtd="0.9144">
       <irrmeth id="3" eff="0.8" arzi="0.5" exir="0.4"></irrmeth>
       <irrmgmt trigcode="0"></irrmgmt>
     </afirr>
     <afsoil label="0.8  SOILS" depth="2.4384" minwc=".08" maxwc=".08"
             cond="1"> </afsoil>
   </ramcc> </hpmEntry>
```

Figure 2.2 **`ramcc.xml`** XML for HPMs for Benchmark 33r (continued)

```
    <hpmEntry id="9" label="rice - seepage irrigation">
      <ramcc>
        <afcrop label="rice" id="49" j1="01-01" jn="04-30"
                depth1="0.3048" depth2="0.4572">
          <kctbl>
            1.20 1.05 0.25 0.25 0.25 0.25
          </kctbl>
          <awdtbl>
            0.00 0.00 0.00 0.00
          </awdtbl>
        </afcrop>
        <afirr label="SEEPAGE IRRIGATION" wtd="0.9144">
          <irrmeth id="9" eff="0.8" arzi="1.0" exir="1.0"
                   drinc="1.0"></irrmeth>
          <irrmgmt trigcode="0"></irrmgmt>
        </afirr>
        <afsoil label="0.8  SOILS" depth="2.4384" minwc=".25" maxwc=".50"
                cond="1"> </afsoil>
      </ramcc>
    </hpmEntry>

    <hpmEntry id="10" label="fall rice - seepage irrigation">
      <ramcc>
        <afcrop label="rice" id="49" j1="09-01" jn="12-31"
                depth1="0.3048" depth2="0.4572">
          <kctbl>
            1.20 1.05 0.25 0.25 0.25 0.25
          </kctbl>
          <awdtbl>
            0.00 0.00 0.00 0.00
          </awdtbl>
        </afcrop>
        <afirr label="SEEPAGE IRRIGATION" wtd="0.9144">
          <irrmeth id="9" eff="0.8" arzi="1.0" exir="1.0"
                   drinc="1.0"></irrmeth>
          <irrmgmt trigcode="0"></irrmgmt>
        </afirr>
        <afsoil label="0.8  SOILS" depth="2.4384" minwc=".20" maxwc=".45"
                cond="1"> </afsoil>
      </ramcc>
    </hpmEntry>
  </indexed>
</hpModules>
```

Figure 2.2 **`ramcc.xml`** XML for HPMs for Benchmark 33r (continued)

Exercise 2.1.2 Benchmark 37 (SVconverter)

Benchmark 37 illustrates the impact of variable microtopography and drainable soil water storage on the cell heads under well pumping stress.

The SVconverter is the method used by the RSM to convert from head to volume within a waterbody. In the simplest case, the drainable soil water storage can be set to the specific yield for the aquifer which is typically assumed to be 0.2 m/m. This does not represent the effect of microtopography and soil water storage on drainage. The gradation from the constant specific yield of the unconfined aquifer (0.2) to inundation (specific yield = 1.0) can be represented using a rulecurve.

The <rulecurve> element for the SVconverter (see **Fig. 2.3**) provides the cumulative storage for the SVconverter from a specified depth below ground. The interpretation of the cumulative storage into porosity is given in **Table 2.1**.

Table 2.1 SVconverter rulecurve

Depth = H - (Z-below)	Cumulative storage	Elevation	Porosity
0.0	0.00	498.5	0.2
0.2	0.04	498.7	0.2
0.4	0.12	498.9	0.4
0.8	0.36	499.3	0.6
1.0	0.56	499.5	1.0
2.0	1.56	500.5	1.0
3.0	2.56	501.5	1.0

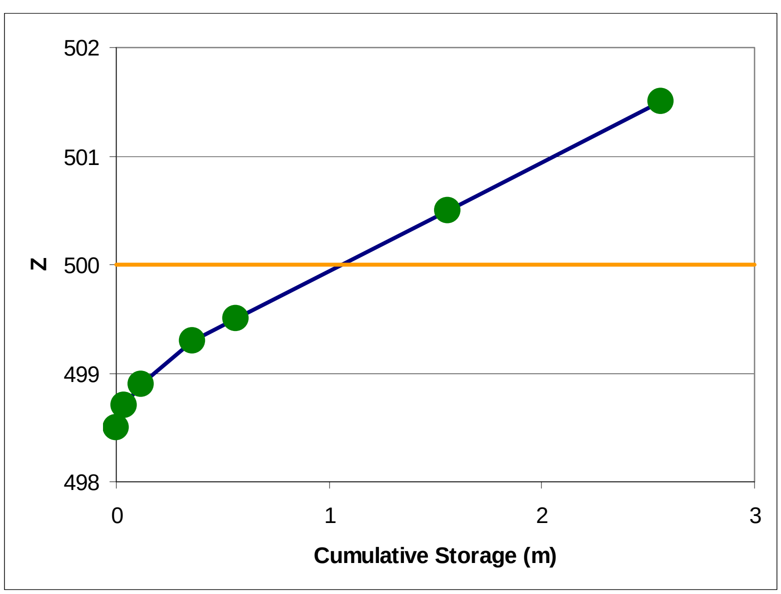


Figure 2.3 Cumulative specific yield for SVconverter used in Benchmark 37

In this benchmark, pumping stress is applied to the mesh by four wells. The stress is applied by a time series of alternating inflow and outflow. The output monitors the resulting impact on the cell heads.

1. Draw the layout of the benchmark mesh by hand and locate the wells in the appropriate cells. You can use the mesh in **`$RSM/labs/lab2_BM2/mesh.ppt`** as a starting point.
   - Using HEC-DSSVue from the RSM GUI toolbar and selecting **`well.dss`**, create a plot of the well stress for the period of the simulation.

The period of the simulation is determined by the start and end times specified in the <**`control`**> block. In DSSVue, you can zoom-in by selecting the portion of the x-axis you wish to display.

In the **`run3x3.xml`** you will notice that the <**`svconverter`**> element has an <**`indexed`**> subelement that identifies a file (**`sv.index`**) that specifies cells to which the different SVconverter constructs are applied (see **Fig. 2.4)**.

2. Determine which cells have which SVconverter type:
   - List the **`sv.index`** file
   - Locate the different svconverter types on the appropriate cells
3. Run the benchmark and graph the results:
   - Run **`BM37/run3x3.xml`** using the RSM GUI
   - Run HEC-DSSVue from the RSM GUI and select **`t3x3out.dss`**.
4. Observe the change on water table heads with time.

NOTE:

For more information about HEC-DSSVue, refer to pp. 4-16 in the *HEC-DSSVue User's Manual,* which is available online:

http://www.hec.usace.army.mil/software/hec-dss/hecdssvue-documentation.htm

```
<?xml version="1.0"?>
<!DOCTYPE hse SYSTEM "../hse.dtd" [
]>
<hse>
  <control
       tslen="15"   tstype="minute"
       startdate="01jan1994"   starttime="0000"    enddate="01jan1994"   endtime="0230"
       alpha="0.500"    solver="PETSC"   method="gmres"   precond="ilu">
  </control>

  <mesh>
       <geometry file="mesh3x3.2dm"> </geometry>
       <mesh_bc>
          <well cellid="1" wmID="1" label="well">
                <dss file="well.dss" pn="/HSE/T3X3 WEL/VOLUME/01JAN1994/15MIN/CALC/"></dss>
          </well>
          <well cellid="10" wmID="2" label="well">
               <dss file="well.dss" pn="/HSE/T3X3 WEL/VOLUME/01JAN1994/15MIN/CALC/"></dss>
          </well>
          <well cellid="9" wmID="3" label="well">
               <dss file="well.dss" pn="/HSE/T3X3 WEL/VOLUME/01JAN1994/15MIN/CALC/"></dss>
          </well>
          <well cellid="18" wmID="4" label="well">
               <dss file="well.dss" pn="/HSE/T3X3 WEL/VOLUME/01JAN1994/15MIN/CALC/"></dss>
          </well>
       </mesh_bc>
       <shead>    <gms file="hin3x3.dat">   </gms>    </shead>
       <bottom>  <const value="0.0">   </const> </bottom>
       <surface> <const value="500.0"> </const> </surface>
       <conveyance>   <mannings a="1.000" detent="0.00001"></mannings>  </conveyance>
       <transmissivity>  <unconfined k = "0.0"> </unconfined>  </transmissivity>

       <svconverter>
           <indexed file="sv.index">
                <entry id="1" label="const">   <constsv sc="0.2"> </constsv>   </entry>
                <entry id="2" label="lookup">
                      <lookupsv sc="0.2" below="1.5" above="1.0">
                           <sv>
                           0.0   0.0
                           0.2   0.04
                           0.4   0.12
                           0.8   0.36
                           1.0   0.56
                           2.0   1.56
                           3.0   2.56
                           </sv>
                      </lookupsv>
                </entry>
           </indexed>
       </svconverter>
  </mesh>
```

Figure 2.4 XML input for the <**mesh**> element block for **run3x3.xml** for Benchmark 37 (SVconverter)

Exercise 2.1.3 Benchmark 54 (HPM hubs)

Benchmark 54 (BM54) illustrates the RSM's ability to simulate multiple land uses within a single HPM with the capability for a single water supply and a single drainage. The main XML run file (**`run3x3.xml`**) has several XML files listed at the top of file (see **Fig. 2.5**). The ampersand "&" symbol in the body of the **`run3x3.xml`** and **`hpms.xml`** files indicates implemented XML (refer to **Fig. 2.6**).

In the typical urban land type hub (**`hpms.xml`**) there is impervious land that drains to pervious land that drains to a detention pond that drains to Waterbody 14.

5. To understand the layout of the benchmark, draw the typical benchmark grid and identify the location of the HPMs and their water supply and runoff assignment cells using the locations from the **`lu.index`** file.
6. Run BM54:
    - **`cd $RSM/benchmarks/BM54`**
7. From the RSM GUI, run **`BM54/run3x3.xml`**
8. Identify the output from benchmark 54
9. Run hpmbud for Cell 1 and Cell 14
    - Create two new files: file **"`cell1`"** should have one value, **"`1`"**, and file "**`cell14`**" should have one value, **"`14`"**.

```
$RSM/hpmbud/hpmbud –n hpmBudget.nc –s cell1 –d –m 12
$RSM/hpmbud/hpmbud –n hpmBudget.nc –s cell14 –d –m 12
```

    - What are the differences?
10. Add the water budget package:
    - **`gedit run3x3.xml`**
    - Add the syntax to the output block for the water budget package:

```
<wbbudgetpackage file="wbbudget.nc" />
```

    - Delete the <**`budgetpackage`**> element
    - Run the RSM
11. Run the wbbud from the RSM GUI water budget for waterbody ID 1 and ID 14

- Run **wbbud** from the **RSM GUI** using the following settings:

  - File **`./RSM/trunk/benchmarks/BM54/wbbudget.nc`**
  - Select **`Depth transform`** option
  - Select **`Subset`** option
  - Enter single value of **`1`** into the **`IDs subset`** input field
  - Enter multiplier of **`12`** to convert feet to inches
  - Type **`inches`** into the units input field
  - Select **`Month`** format option
  - Enter location and **`filename`** for the output file to be generated
  - Click Next >> to generate the wbbud tool

12. Run wbbud from the RSM GUI again for waterbody ID 14 and save output to a file for comparison.
    - What are the differences?
13. In order to look at heads in Cell 1 and Cell 14, you need to add cell monitors for head:
    - Copy monitor from **`BM33/run3x3.xml`**

```
<cellmonitor id="1" attr="head">
<dss file="head1.dss" pn="/c1/citrus/head//1day/micro/"></dss>
</cellmonitor>
```

14. Create a file with value “14” in it, similar to the file “cell 14”.
15. Run the RSM
    - What are the differences in the heads?
16. Change the runoff in **`hpmEntry-ID="2"`** for the landscape HPM (**`hubmember-ID="2"`**) to go to Cell 14 (**`runoff="wb-14"`**) rather than the detention pond (**`runoff="hpm-1"`**)
17. Run the RSM
    - What are the differences in head and water budgets?

```
<?xml version="1.0" ?>
<!DOCTYPE hse SYSTEM "../hse.dtd" [
<!ENTITY hpm SYSTEM "hpm.xml">
<!ENTITY landscape SYSTEM "landscape.xml">
<!ENTITY layer5 SYSTEM "layer5.xml">
<!ENTITY layer1nsm SYSTEM "layer1nsm.xml">
<!ENTITY urbandet SYSTEM "urbandet.xml">
]>
<hse version="0.1">
  <control
    tslen="24" tstype="hour" startdate="01jan1965" starttime="0000"
    enddate="31dec1966"  endtime="2400" alpha="0.500"
    solver="PETSC"  method="gmres"  precond="ilu">
  </control>

  <mesh>
    <geometry file="mesh3x3.2dm"> </geometry>
    <mesh_bc>
      <wallhead section="gw">  <nodelist> 5 9 </nodelist>
        <uniform> <const value="498.0"> </const> </uniform>
      </wallhead>
      <wallhead section="gw"> <nodelist> 8 12 </nodelist>
        <uniform> <const value="498.0"> </const> </uniform>
      </wallhead>
    </mesh_bc>
    <shead><gms file="hin3x3.dat"></gms></shead>
    <rain>
      <dss file="weather.dss" pn="/LOSA/AREAL/RAINFALL//1DAY/ESTIMATED/"
        mult="0.0254" units="INCHES">
      </dss>
    </rain>
    <refet>
      <dss file="weather.dss" pn="/LOSA/AREAL/REFET//1DAY/ESTIMATED/"
        mult="0.0254" units="INCHES">
      </dss>
    </refet>
    <bottom>  <const value="0.0">   </const> </bottom>
    <surface> <gms file="selev.gms"> </gms> </surface>

    &hpm;

    <conveyance>
      <mannings a="1.000" detent="0.00001"></mannings>
    </conveyance>
    <transmissivity> <unconfined k = "0.02"> </unconfined>
</transmissivity>

    <svconverter>
      <constsv sc="0.2"> </constsv>
    </svconverter>
  </mesh>
  <output>
    <hpmbudgetpackage file="hpm.nc" dbintl="43200"></hpmbudgetpackage>
  </output>
</hse>
```

Figure 2.5 run3x3.xml for Benchmark 54 (hubs)

```xml
<hpModules>
  <indexed file="lu.index">

    <!-- unsat -->
    <hpmEntry id="1">
      <hub runoff="homecell" wsupply="homecell">
        <hubMember id="1" percentarea="100" runoff="hub">
          <unsat ew="0.2" kw="1.0" rd="0.5" xthresh="0.02"
            pthresh="0.10" pd="3.0" kveg="0.75">
          </unsat>
        </hubMember>
      </hub>
    </hpmEntry>

    <!-- impervious routed to landscape routed to detention area -->
    <!-- runoff (detention area outlet) discharged to cell #14   -->
    <!-- water supply (landscaping) withdrawn from cell #14      -->
    <hpmEntry id="2">
      <hub runoff="wb-14" wsupply="wb-14">
        <hubMember id="1" percentarea="10" runoff="hub">
          &urbandet;
        </hubMember>
        <hubMember id="2" percentarea="20" runoff="hpm-1" wsupply="hub">
          &landscape;
        </hubMember>
        <hubMember id="3" percentarea="70" runoff="hpm-2">
          <imperv sdet="0.1" isto="0.01"></imperv>
        </hubMember>
      </hub>
    </hpmEntry>

    <!-- impervious (dirconn) routed to landscape routed to   -->
    <!-- urban detention                                      -->
    <!-- runoff (detention area outlet) discharged to cell #4 -->
    <!-- water supply (landscaping) withdrawn from cell #5    -->
    <hpmEntry id="3">
      <hub runoff="wb-5" wsupply="wb-5">
        <hubMember id="1" percentarea="10" runoff="hub">
          &urbandet;
        </hubMember>
        <hubMember id="2" percentarea="20" runoff="hpm-1" wsupply="hub">
          &landscape;
        </hubMember>
        <hubMember id="3" percentarea="70" runoff="hpm-1">
          <imperv sdet="0.1" isto="0.01" dirconn="1"></imperv>
        </hubMember>
      </hub>
    </hpmEntry>

  </indexed>
</hpModules>
```

Figure 2.6 XML for HPMs for Benchmark 54 (hubs)

Exercise 2.1.4 Run Benchmark 65 (Water Control District)

Benchmark 65 is designed to demonstrate the use of a Water Control District (WCD) to represent secondary water management systems that are connected to the Central and Southern Florida Flood Control Project (C&SF Project) primary system of canals and levees that are explicitly simulated in the RSM.

A Water Control District consists of a lake or large canal system that was created as a borrow area from which home sites can be built up while creating local stormwater detention storage. These lakes or canals can have substantial storage volume.

A WCD canal system is modeled as a **<wcdwaterbody>** that is connected to mesh cells through seepage and overbank flow watermovers. The length of the connection between the canal and the cell typically is determined from an aerial photograph. There is a designated watermover that represents a pump or weir that connects the **<wcdwaterbody>** to the primary canal system.

The WCD is sensitive to the stage-storage relationship in the **<wcdwaterbody>**, particularly as the waterbody approaches full bank conditions and the stage-storage accounts for flooding storage. The WCD is also sensitive to the amount of interaction (**seglength** and **segwidth**) between the **<wcdwaterbody>** and the adjacent cells; if there is too much interaction, then there is no effective storage in the **<wcdwaterbody>**.

18. To understand the layout of the benchmark, draw the typical benchmark grid and identify the location of the wcdwaterbody contact with the mesh cells and locate the cells that connect the wcdwaterbody to the mesh (See **Fig. 2.7**).
19. Draw the stage-storage curve by hand or with a spreadsheet in the range of water levels in this model (495–505 feet) from the storage-volume **<SV>** element of **<wcdwaterbody>**.
    - Note the shape of the relationship.
        - What are the IDs for the watermovers connecting the wcdwaterbody to the mesh?
        - Locate the canal network. Where does it lie?

Sometimes it is useful to create an artificial waterbody that represents either an unknown source/sink or a waterbody that is outside the domain of interest.

In BM65e a canal has been created with a head boundary condition to represent a canal that is not being modeled. Head and flow monitors are placed on the canal to monitor the flow from the wcdwaterbody.

```xml
<?xml version="1.0"?>
<!DOCTYPE hse SYSTEM "./hse.dtd" [
<!ENTITY hpms     SYSTEM "hpms.xml">
]>
<hse>

  <control
    tslen="24"  tstype="hour"  startdate="01jun1965"  starttime="0000"
    enddate="30jun1965"  endtime="0000"  alpha="0.9000"   solver="PETSC"
    method="gmres"  precond="ilu">
  </control>

  <network>
    <geometry file="canal3x3.map"> </geometry>
    <initial file="canal3x3.init"> </initial>
    <arcs>
      <indexed file="arcs.index">
        <xsentry id="1">
          <arcflow n="0.2"></arcflow>
          <arcseepage leakage_coeff="0.000405"></arcseepage>
          <arcoverbank bank_height="0.3" bank_coeff ="0.001">
          </arcoverbank>
        </xsentry>
      </indexed>
    </arcs>
   <network_bc>
      <segmenthead id="22" label="constant head">
         <const value="498.0"></const>
      </segmenthead>
    </network_bc>
  </network>

  <mesh>
    <geometry file="mesh3x3.2dm"> </geometry>
    <shead><gms file="hin3x3.dat"></gms></shead>
    <bottom>  <const value="0.0">   </const> </bottom>
    <surface> <const value="500.0"> </const> </surface>
    <conveyance>   <mannings a="0.200" detent="0.00001"></mannings>
    </conveyance>
    <transmissivity>  <unconfined k = "0.00002"> </unconfined>
    </transmissivity>
    <svconverter>  <constsv sc="0.2"></constsv>  </svconverter>
    <rain>
      <dss file="weather.dss" pn="/SFWMM/WPB-BSN/RF//1DAY/HIST/"
            mult="0.0254" units="INCHES"> </dss>
    </rain>
    <refet>
      <dss file="weather.dss" pn="/SFWMM/WPB-BSN/PET//1DAY/HIST/"
            mult="0.0254" units="INCHES">  </dss>
    </refet>
    &hpms;
  </mesh>
```

Figure 2.7 Input XML code for run3x3.xml for Benchmark 65: (Water Control Districts)

```
<wcdwaterbodies  initialcondfile = "initconda.dat">
  <wcdwaterbody id="101" name="acme1">
      <sv>
         495          0    } Stage-volume converter
         496    2000000
         520   40000000
      </sv>
      <wcdmover cellid="1" seepid="30001"  bankid="30002"
      segwidth="30"     seglength="5000"
      botelv="490"
      leakagecoeff="0.00001"
      bankheight=".01" bankcoeff="0.02" />

      <wcdmover cellid="10" seepid="30003"  bankid="30004"
      segwidth="20"     seglength="5000"
      botelv="490"
      leakagecoeff="0.00004"
      bankheight=".001"  bankcoeff="0.02" />
     </wcdwaterbody>
</wcdwaterbodies>

<watermovers>
<single_control id1="101" id2="19" wmID="7" control="101" cutoff="497.5"
                gravflow="no" revflow="no" label="test struct" >
      497      0
      497.5    0
      498      0
      499.5   25   } Pump size (cfs)
      500     75
      510    100
</single_control>
</watermovers>

  <output>
    <wcdmonitor id="101" attr="head">
        <dss file="out.dss" pn="/hse/wcd101/head//1day/calc/"></dss>
    </wcdmonitor>
    <wcdmonitor id="101" attr="flow" wmid="30001">
        <dss file="out.dss" pn="/hse/wcdwm30001/flow//1day/calc/"></dss>
    </wcdmonitor>
    <wcdmonitor id="101" attr="flow" wmid="30002">
        <dss file="out.dss" pn="/hse/wcdwm30002/flow//1day/calc/"></dss>
    </wcdmonitor>
    <wcdmonitor id="101" attr="flow" wmid="30003">
        <dss file="out.dss" pn="/hse/wcdwm30003/flow//1day/calc/"></dss>
    </wcdmonitor>
    <wcdmonitor id="101" attr="flow" wmid="30004">
        <dss file="out.dss" pn="/hse/wcdwm30004/flow//1day/calc/"></dss>
    </wcdmonitor>
    <wmmonitor wmID="7" attr="flow">
        <dss file="out.dss" pn="/hse/wcdwmt/flow//1day/calc/"></dss>
    </wmmonitor>
```

Figure 2.7 Input XML code for run3x3.xml for Benchmark 65 (continued)

```
    <segmentmonitor id="20" attr="head">
          <dss file="out.dss" pn="/hse/s20/head//1day/calc/"></dss>
    </segmentmonitor>

    <cellmonitor id="1" attr="head">
       <dss file="out.dss"  pn="/hse/c01/head//1day/calc/"></dss>
    </cellmonitor>
    <cellmonitor id="10" attr="head">
       <dss file="out.dss" pn="/hse/c10/head//1day/calc/"></dss>
    </cellmonitor>
    <cellmonitor id="3" attr="head">
       <dss file="out.dss" pn="/hse/c03/head//1day/calc/"></dss>
    </cellmonitor>
    <cellmonitor id="4" attr="head">
       <dss file="out.dss" pn="/hse/c04/head//1day/calc/"></dss>
    </cellmonitor>
    <cellmonitor id="5" attr="rain">
       <dss file="out.dss" pn="/hse/c05/rain//1day/calc/"></dss>
    </cellmonitor>
    <cellmonitor id="7" attr="head">
       <dss file="out.dss" pn="/hse/c07/head//1day/calc/"></dss>
    </cellmonitor>
    <cellmonitor id="8" attr="head">
       <dss file="out.dss" pn="/hse/c08/head//1day/calc/"></dss>
    </cellmonitor>

    <budgetpackage file="budget.nc"></budgetpackage>
    <hpmbudgetpackage file="hpmbudget.nc"></hpmbudgetpackage>
    <budget file="budgeta.dat"></budget>

    <globalmonitor attr="head  <gms file="outheads.dat"> </gms>
    </globalmonitor>
    <globalmonitor attr="head" >  <netcdf file="test2a.nc"></netcdf>
    </globalmonitor>
    <globalmonitor attr="wcdbankvolume" >
       <netcdf file="test2a.nc">  </netcdf>
    </globalmonitor>
    <globalmonitor attr="wcdwaterbodyhead" >
      <netcdf file="test2a.nc">  </netcdf>
   </globalmonitor>
  </output>
</hse>
```

Figure 2.7 Input xml code for run3x3.xml for Benchmark 65 (continued)

20. Run BM65e **`cd $labs/lab2_BM2/BM65e`**
21. From the RSM GUI, run **`BM65e/run3x3.xml`**
22. Observe the behavior of the WCD through the cell heads and watermover flows
23. Graph the cell heads:
    - Select HEC-DSSVue from the RSM GUI
    - Select **`out.dss`** and plot "**`heads`**" for the cells and wcdwaterbody

NOTE:

The heads vary near the wcdwaterbody, but vary little away from the wcdwaterbody.

24. Select and plot "**`flows`**" for the wcdwaterbody, the pump which is modeled as a single-control watermover, and the canal.

    There are several sensitive parameters in the wcdwaterbody. These include the stage-volume relationship (SV), the pump size, and the leakage and bank coefficients.

25. Notice that there was a high stage in the wcdwaterbody. Adjust the sensitive parameters in the input XML to improve the performance of the wcdwaterbody for retaining water within the WCD and maintaining the water table within an acceptable range (0–1 meters deep).
    - Record the parameter changes and graph the results.

Exercise 2.1.5 Benchmark 66 (levee seepage)

Benchmark 66 (BM66) is designed to demonstrate the levee seepage feature in the RSM and the use of the <**`globalmonitor`**> for creating animations. The regional water management system of the Central and Southern Florida Flood Control Project (C&SF Project) is created with a combination of canals and levees.

The levees are intended to protect downstream areas such as the Everglades Agricultural Area (EAA) and the Lower East Coast from flooding. In other cases, such as the water conservation areas, the levees are designed to retain the water.

Where there is a levee there is an adjacent canal. The levees do not work perfectly and in addition to the regional groundwater flow, there are three pathways of seepage **(Fig. 2.8)**:

- Qms - Seepage from the marsh into the canal
- Qds - Seepage from the dry cell to the canal
- Qmd - Seepage from the marsh under the canal to the dry cell

With the creation of these seepage watermovers, the default watermovers from Cell 7 and Cell 17 to Segment 19 are disabled. The flows in the seepage watermovers can be adjusted in the model through the K terms: Kms, Kds and Kmd.

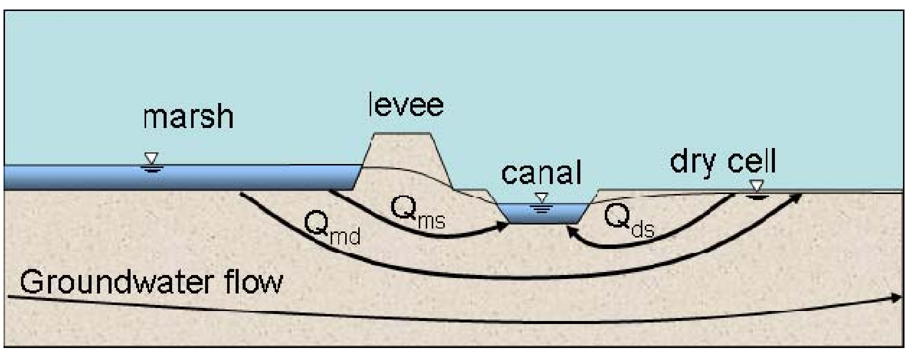


Figure 2.8 Levee seepage to an adjacent borrow canal from the marsh and the neighboring dry cell.

26. Locate the levee cells by drawing the benchmark mesh and canal based on the **mesh3x3.2dm** and **canal3x3.map** files

27. Modify the benchmark **run3x3.xml** file with the following information:
    - Change initial head in the canal segments to **499.5 m [canal3x3.init]**
    - Add a segmentghb boundary condition to the network block of the **run3x3.xml** file:

```
<network_bc>
<segmentghb id="22" bcID="4000" kcoef="10.0" label="TW">
<const value="499.0"></const>  </segmentghb>
</network_bc>
```

    - Add a noflow boundary condition to the mesh:

```
<mesh_bc>
  <noflow section= "ol_gw"> <nodelist> 10 14 </nodelist>
  </noflow>
</mesh_bc>
```

    - Add cellmonitors for head in Cell 7, Cell 1 and Cell 17, using the following template:

```
<cellmonitor id="7" attr="head" label="c7"> <dss file="heads" />
</cellmonitor>
```

    - Add segment monitors for head in each of the segments, using the following template:

```
<segmentmonitor id="19" attr="head" label="s19">
  <dss file="heads" />
</segmentmonitor>
```

    - Add watermover monitors for flow to the three leveeSeepage flows, using the following template:

```
<wmmonitor wmID="1001" attr="flow" label="wm1001">
  <dss file="heads" />
</wmmonitor>
```

    - Modify the canal map so that the coordinate of the first node is (**1.0, 5001**)
    - Modify the initial head in Cell 7 to **502.0 m. [hin3x3.dat]**

28. Run BM66
    - **cd $RSM/benchmarks/BM66**

29. From the RSM GUI, run **BM66/run3x3.xml**

30. Observe resulting head and flows using HecDssVue
31. Modify the seepage characteristics and observe the results:
    - **`gedit run3x3.xml`**
32. Increase the seepage flow Qms by changing the seepage coefficient Km**s** from **`0.2`** to **`0.4`** (see **Fig. 2.10**)
33. Rerun the RSM
34. Observe the results

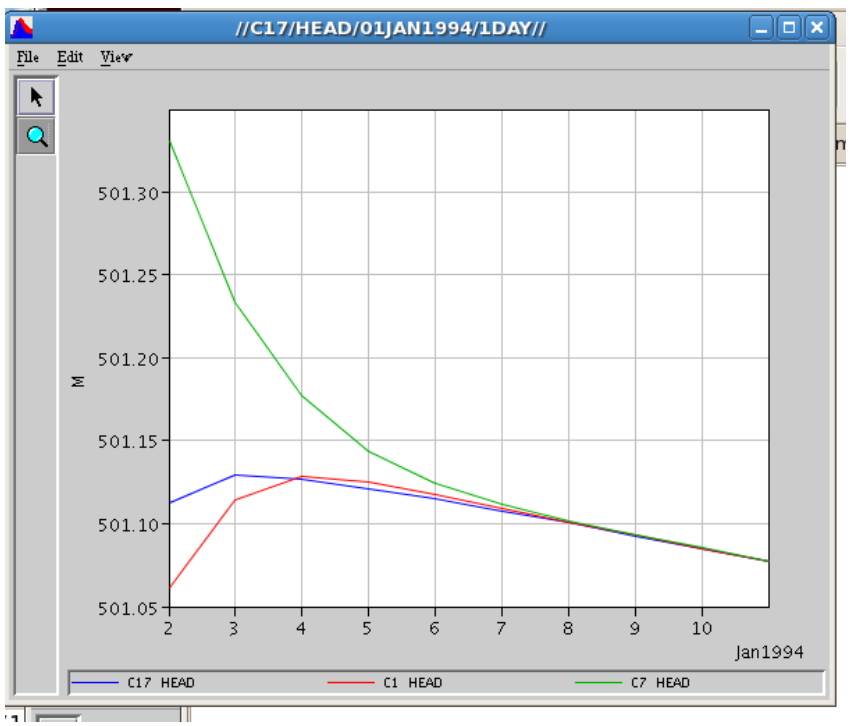


Figure 2.9a Cell head for BM66

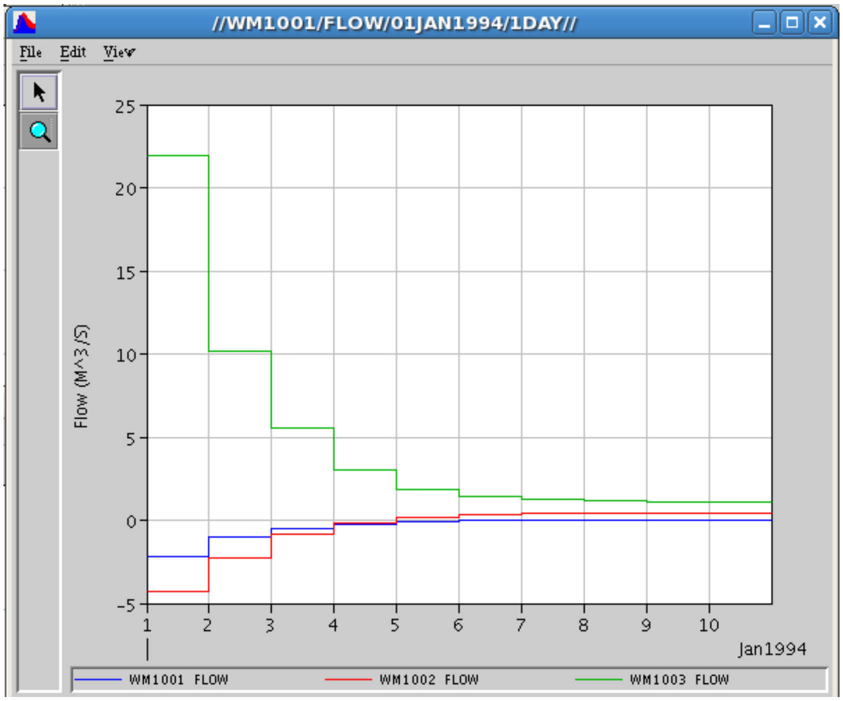


Figure 2.9b LeveeSeepage flows for BM66

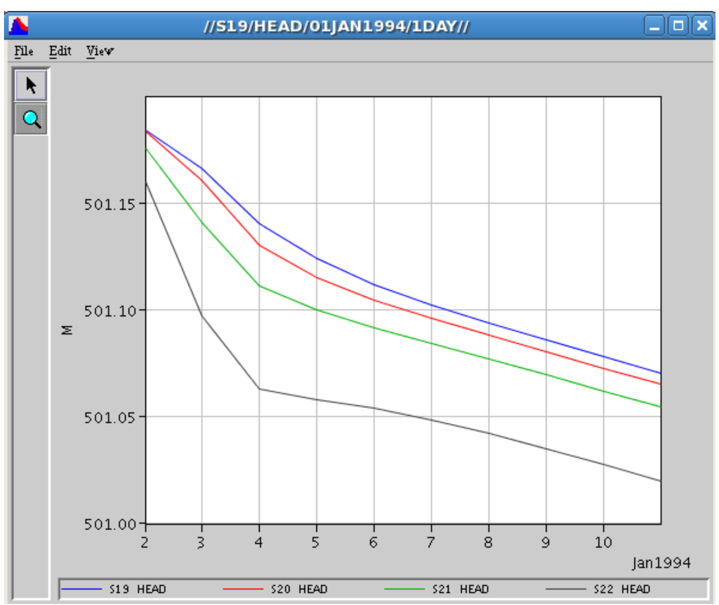


Figure 2.9c Canal segment head for BM66

```
<?xml version="1.0" ?>
<!DOCTYPE hse SYSTEM "../hse.dtd" [
]>
<hse version="0.1">
  <control
    tslen="1" tstype="day"
    startdate="01jan1994" starttime="0000" enddate="10jan1994" endtime="0230"
    solver="PETSC" method="gmres" alpha="1.00" precond="ilu">
  </control>
  <network>
    <geometry file="canal3x3.map"> </geometry>
    <initial file="canal3x3.init"> </initial>
    <arcs>
      <indexed file="arcs.index">
        <xsentry id="1">
          <arcflow n="0.2"></arcflow>
          <arcseepage leakage_coeff="0.000405" />
          <arcoverbank bank_height="0.001" bank_coeff="0.001"/>
        </xsentry>
       <xsentry id="2">
          <arcflow n="0.2"></arcflow>
          <arcseepage leakage_coeff="0.0" />
          <arcoverbank bank_height="0.00" bank_coeff="0.0"/>
        </xsentry>
      </indexed>
    </arcs>
  </network>

  <mesh>
    <geometry file="mesh3x3.2dm"> </geometry>
    <shead><gms file="hin3x3.dat"></gms></shead>
    <bottom>  <const value="0.0">   </const> </bottom>
    <surface> <const value="500.0"> </const> </surface>
    <conveyance> <mannings a="1.000" detent="0.00001"></mannings> </conveyance>
    <transmissivity>  <unconfined k = "0.02"> </unconfined>  </transmissivity>
    <svconverter> <constsv sc="0.2"> </constsv> </svconverter>
 </mesh>
  <watermovers>
   <leveeSeepage>
      <MarshCellToDryCell MarshCellId="17" DryCellId="7"
                          K_md=".1" length="100" wmID="1001" />
      <MarshCellToSegment MarshCellId="17" SegmentId="19"
                          K_ms=".2" length="300"  wmID="1002"/>
      <DryCellToSegment DryCellId="7" SegmentId="19"
                          K_ds=".3" length="500"  wmID="1003"/>
   </leveeSeepage>
  </watermovers>
    <output>
    <budgetpackage file="budget.nc"></budgetpackage>
    <globalmonitor attr="topo"><netcdf file="heads.nc"></netcdf></globalmonitor>
    <globalmonitor attr="head"><netcdf file="heads.nc"></netcdf></globalmonitor>
    <globalmonitor attr="segmenthead"><netcdf file="heads.nc"></netcdf>
    </globalmonitor>
 </output>
</hse>
```

Figure 2.10 Unmodified XML for Benchmark 66 (Levee Seepage) with conductivity values highlighted

Exercise 2.1.6 Run Benchmark 71 (Impoundments)

Benchmark 71 (BM71) illustrates the use of impoundments for above-grade water storage facilities. Unlike lakes and ponds which are geographically independent, impoundments sit on top of the mesh and interact directly with the underlying and adjacent mesh cells.

The impoundment footprint covers one or more cells. The impoundment has a vertical seepage component that links it to the cells below the impoundment footprint (**`fullCoverFlag="1"`**) and a horizontal seepage component for the cells that are adjacent to the impoundment (**`fullCoverFlag="0"`**).

35. From the information in the **`run3x3.xml`** file, draw a diagram of the impoundment and the adjacent cells on the typical benchmark mesh
36. Run benchmark BM71 and observe the heads in the impoundment and the adjacent cells:
    - **`cd $RSM/benchmarks/BM71`**
    - From the RSM GUI, run **`BM71/run3x3.xml`**
37. Run HEC-DSSVue from the RSM GUI and open **`t3x3out.dss`**
38. Graph the heads for the cells under the impoundment, the adjacent cells and the edge cells
39. Graph the components of the impoundment budget (rain, ET, seepageflow and head)
40. Modify the seepage coefficients (see **Fig. 2.11**)
    - Edit **`run3x3.xml`**
    - Modify the **`kOverDelV`**, increase the values by **`100x`**
    - Rerun the model and graph the results
    - Edit the **`kOverDelH`**, increase the values by **`100x`**
    - Rerun the model and graph the results

```xml
<?xml version="1.0" ?>
<!DOCTYPE hse SYSTEM "../hse.dtd" []>
<hse>
  <control
    tslen="24"  tstype="hour"  startdate="01jan1994" starttime="0000"
    enddate="10nov1994"  endtime="2400" alpha="0.500"  solver="PETSC"
    method="gmres"  precond="ilu">
  </control>

  <mesh>
      <geometry file="mesh3x3.2dm"> </geometry>
      <shead><gms file="hin3x3.dat"></gms></shead>
      <rain><dss file="rain.dss"
             pn="/C16/AREAL/RAINFALL//1day/R51C39/"></dss></rain>
      <refet> <const value="0.005"> </const> </refet>
      <bottom>  <const value="0.0">   </const> </bottom>
      <surface> <const value="500.0"> </const> </surface>
      <conveyance><mannings a="1.000" detent="0.00001"></mannings>
      </conveyance>
      <transmissivity> <unconfined k = "0.02"> </unconfined>
      </transmissivity>
      <svconverter> <constsv sc="0.2"> </constsv> </svconverter>
      <hpModules>
         <indexed file="lu.index">
           <hpmEntry id="1">
             <unsat ew="0.2" kw="1.0" rd="0.5" xthresh="0.02"
                    pthresh="0.10" pd="1.0" kveg=".85">
             </unsat>
           </hpmEntry>
           <hpmEntry id="3">
            <layer5 ew="0.2" kw="1.0" rd="0.0" xd="0.5" pd="1.0"
                    kveg="0.65">
            </layer5>
          </hpmEntry>
        </indexed>
      </hpModules>
  </mesh>

<impoundments>
  <impoundment id="28" label="Frog Pond Reservoir"  head="501"
               bottom="500" owCoeff="1" swCoeff="1"  swDepth="1">
    <cellConnect cellId="14" fullCoverFlag="1" kOverDelV="0.00000278"
                 SCconf="0.001">
    </cellConnect>
    <cellConnect cellId="5"  fullCoverFlag="1" kOverDelV="0.00000278"
                 SCconf="0.001">
    </cellConnect>
```

Figure 2.11 XML for Benchmark 71 (Impoundment)

```
    <cellConnect cellId="4"  fullCoverFlag="0" kOverDelH="0.0001041">
    </cellConnect>
    <cellConnect cellId="11" fullCoverFlag="0" kOverDelH="0.0001041">
    </cellConnect>
    <cellConnect cellId="15" fullCoverFlag="0" kOverDelH="0.0001041">
    </cellConnect>
    <cellConnect cellId="8"  fullCoverFlag="0" kOverDelH="0.0001041">
    </cellConnect>
  </impoundment>
</impoundments>

<output>
    <cellmonitor id="1" attr="head">
      <dss file="t3x3out.dss" pn="/hse/t3x3 c01/head//1day/calc/"> </dss>
    </cellmonitor>
    <cellmonitor id="14" attr="rain">
      <dss file="t3x3out.dss" pn="/hse/t3x3 c14/rain//1day/calc/"> </dss>
    </cellmonitor>
    <cellmonitor id="14" attr="refet">
      <dss file="t3x3out.dss" pn="/hse/t3x3 c14/refet//1day/calc/"></dss>
    </cellmonitor>

    <impoundmentmonitor id="28" attr="head">
      <dss file="t3x3out.dss" pn="/hse/i28/head//1day/calc/"> </dss>
    </impoundmentmonitor>

    <impoundmentmonitor id="28" attr="seepageflow">
      <dss file="t3x3out.dss" pn="/hse/i28/seepageflow//1day/calc/"></dss>
    </impoundmentmonitor>

    <impoundmentmonitor id="28" attr="rain">
      <dss file="t3x3out.dss" pn="/hse/i28/rain//1day/calc/"> </dss>
    </impoundmentmonitor>

    <impoundmentmonitor id="28" attr="refet">
      <dss file="t3x3out.dss" pn="/hse/i28/refet//1day/calc/"> </dss>
    </impoundmentmonitor>

    <globalmonitor attr="head"> <gms file="outheads.dat"> </gms>
    </globalmonitor>
    <globalmonitor attr="totalvector"> <gms file="Totalvector.dat"> </gms>
    </globalmonitor>

    <budgetpackage file="budget.nc"></budgetpackage>
  </output>
</hse>
```

Figure 2.11 XML for Benchmark 70 Impoundment (continued)

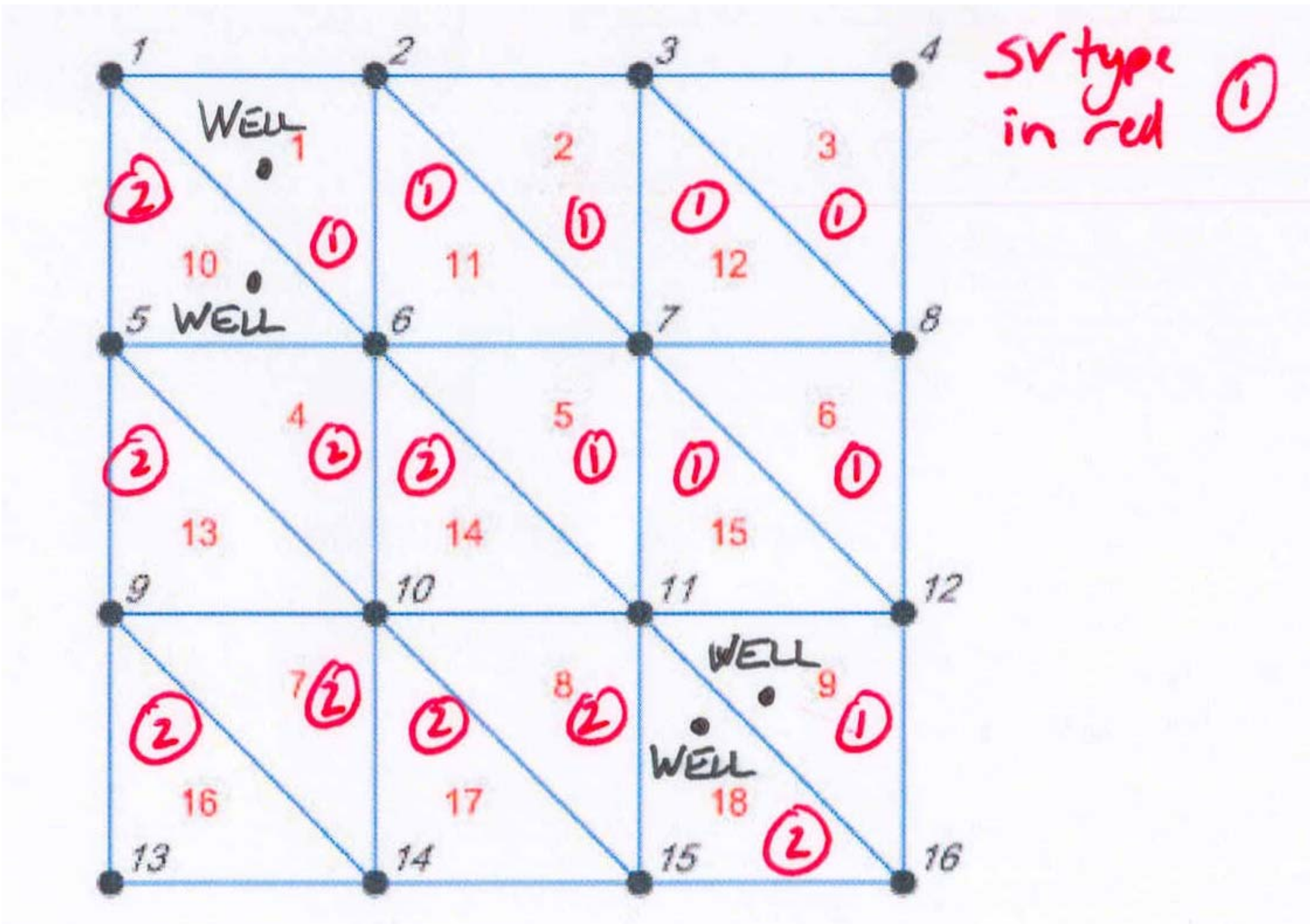
Answers for Lab 2:

Exercise 2.1.1.

<no questions>

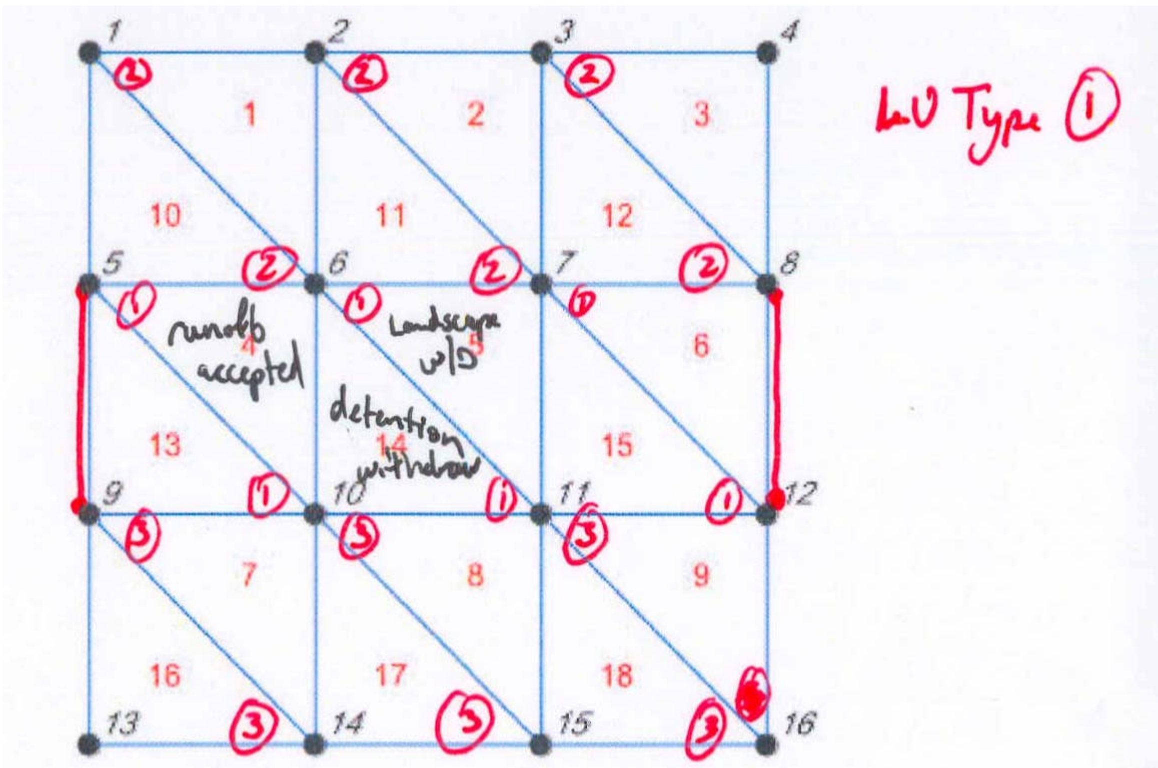
Exercise 2.1.2.

Draw the layout of the benchmark mesh and locate the wells in the appropriate cells.



Exercise 2.1.3.

1. To understand the layout of the benchmark, draw the typical benchmark grid and identify the location of the HPMs and their water supply and runoff assignment cells using the locations from the lu.index file.



5. What are the differences? cell1 is RAMCC, cell14 is unsat

8. What are the differences?

The first implementation of the tool yields monthly volumes in cubic feet of water, while the second yields depth-transformed values in inches over the water shed area, a common way of expressing runoff.

11. What are the differences in the heads?

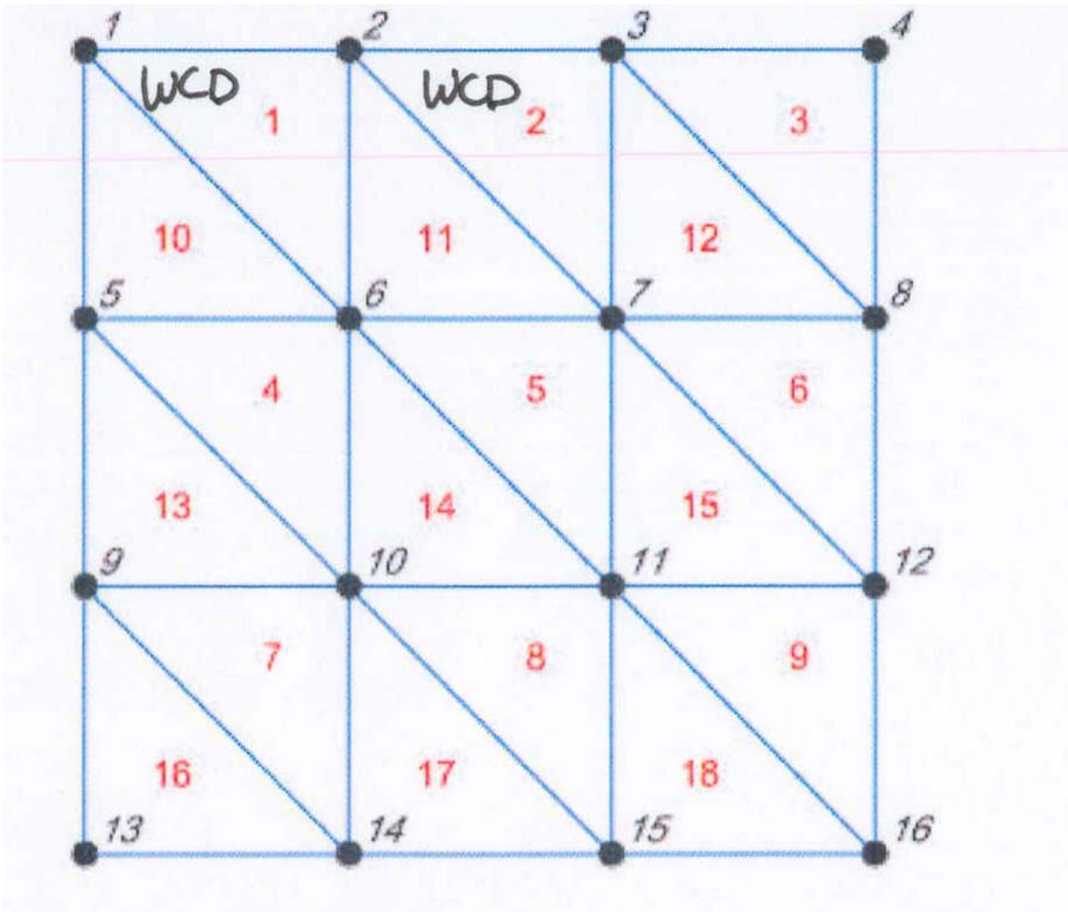
Cell 14 and cell 1 have a similar pattern of heads over the years, however cell 1 has a smooth pattern while cell 14 encounters more spikes in head values. This is because cell 14 holds detention and provides water supply, making it more prone to changes in water level.

13. What are the differences in the heads and the water budgets?

The spikes in head for cell 14 become larger, but the patterns in heads for both cells remain the same. This leads to more instances of sfFlow in the water budget report, but other changes in the budget were not significant.

Exercise 2.1.4.

1. Draw the typical benchmark grid and identify the location of the wcdwaterbody contact with the mesh cells and locate the cell that connects the wcdwaterbody to the mesh



2. Draw the stage-storage curve by hand or with a spreadsheet in the range of water levels in this model (495-505 ft) from the storage-volume <SV> element of <wcdwaterbody>.

What are the IDs for the watermovers connecting the wcdwaterbody to the mesh?

id1=101, id2=8

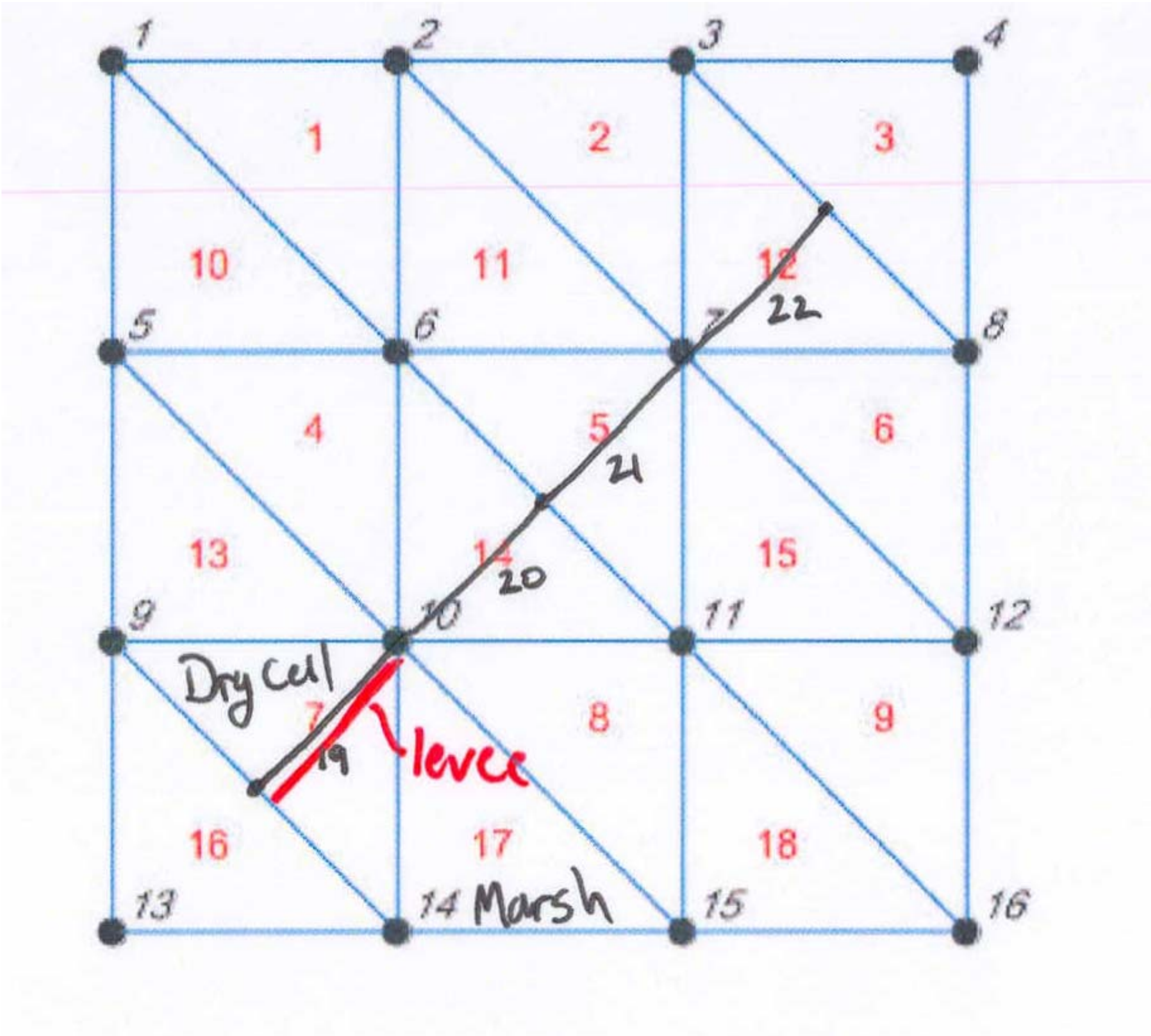
Locate the canal network. Where does it lie?

6. Graph the cell heads

8. Record the parameter changes and graph the results.

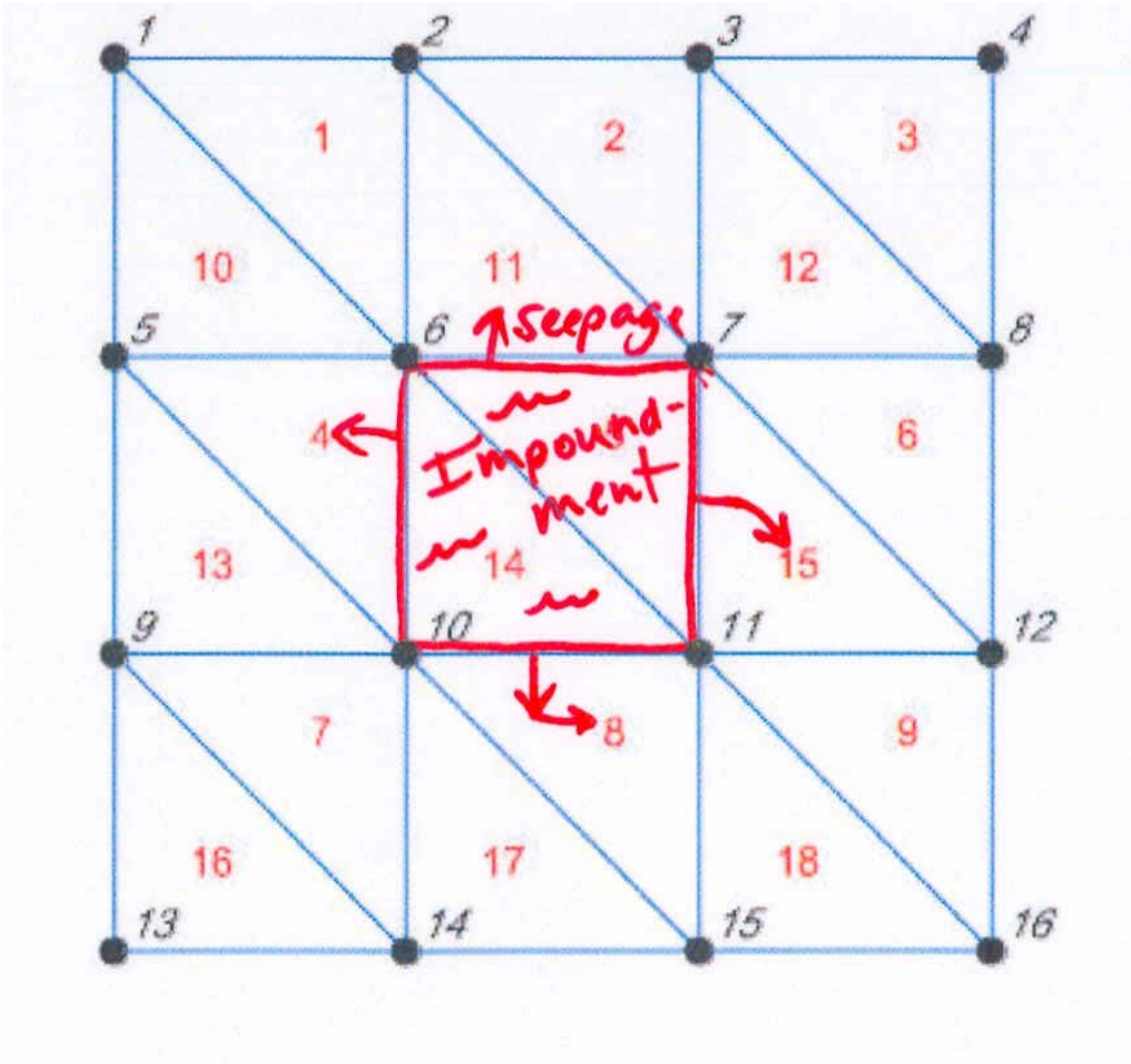
Exercise 2.1.5.

1. Locate the levee cells by drawing the benchmark mesh and canal based on the **`mesh3x3.2dm`** and **`canal.map`**



Exercise 2.1.6.

1. Draw a diagram of the impoundment and the adjacent cells on the typical benchmark mesh



4. Graph the heads for the cells under the impoundment, the adjacent cells and the edge cells.

5. Graph the components of the impoundment budget.

6. Graph the results with kOverDelV x100

   Graph the results with kOverDelH x100

Index