The Story of IGSM/IWFM in California

A Journey Through Time
1989 to Present

Presented by

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A Note of Thanks from both of us

- Dr. Young Yoon, the originator of IGSM
- A long list of people in California, from consultants to staff of public agencies, who have contributed to the development of IGSM, used IGSM, supported IGSM, funded IGSM, enhanced IGSM, and provided feedback
- A long list of people, who have used IWFM, supported IWFM, funded IWFM, enhanced IWFM, and provided feedback

IGSM Development History at a Glance

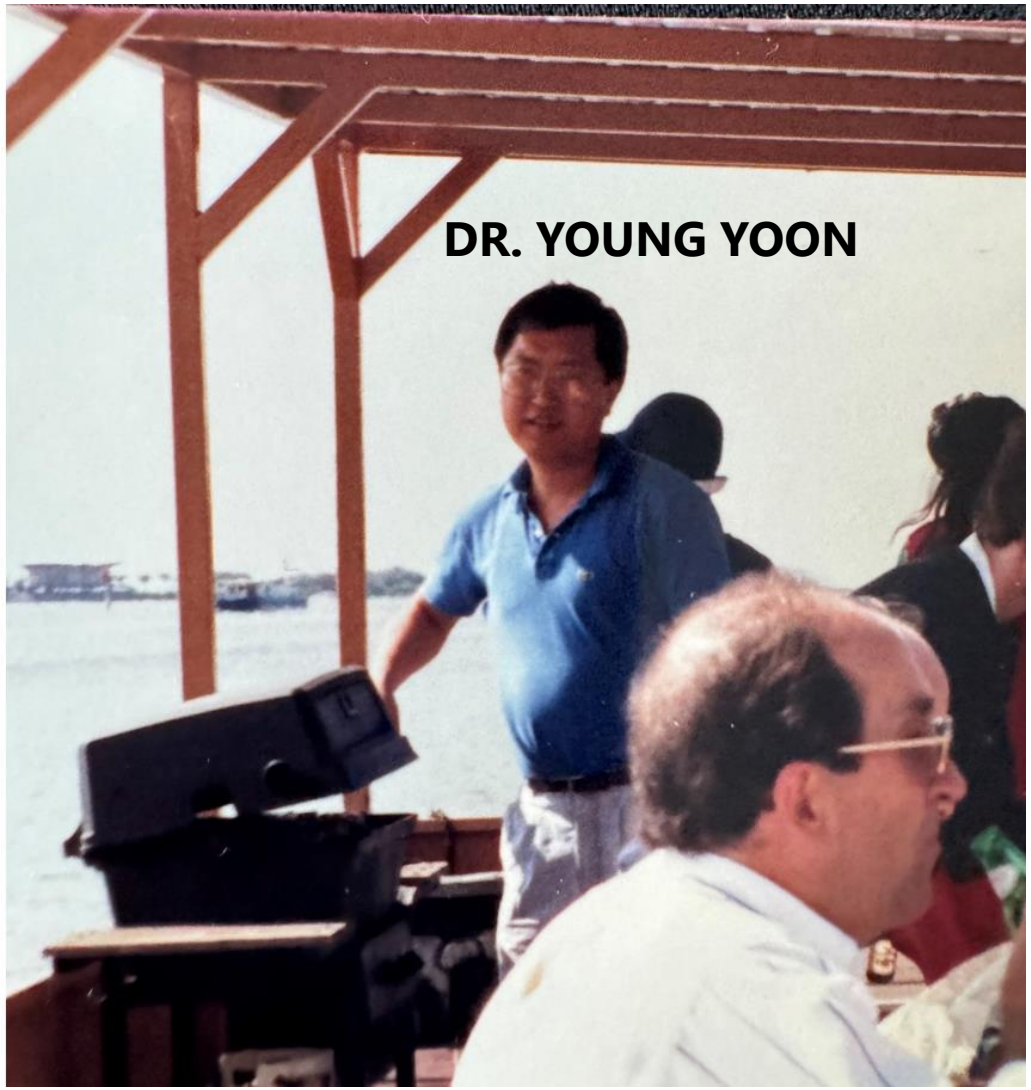
- 1976: FEGW - Initially Developed at UCLA by Dr. Young S. Yoon
- 1982-88: Applied as a Groundwater Model to Small Basins (FEGW14)
- 1989-90: Integrated Groundwater and Surface water Model (IGSM)
  - Dr. Young Yoon
  - Dr. Saquib Najmus, and
  - Dr. Ali Taghavi
  - Application to Central Valley, California (CVGSM)
- 1990-94: Reservoir Ops and Water Quality
- 1995-2010:
  - Ongoing Upgrades and Major Applications
  - Particle Tracking, Daily Simulation
- 2000 Code Handover to DWR

It was 1989
The Dawn of the Internet Age

- Tim Berners-Lee proposed world wide web (www), while working at CERN
- Batman was released in June
- Game Boy released in April
- Computers are like stone age computers

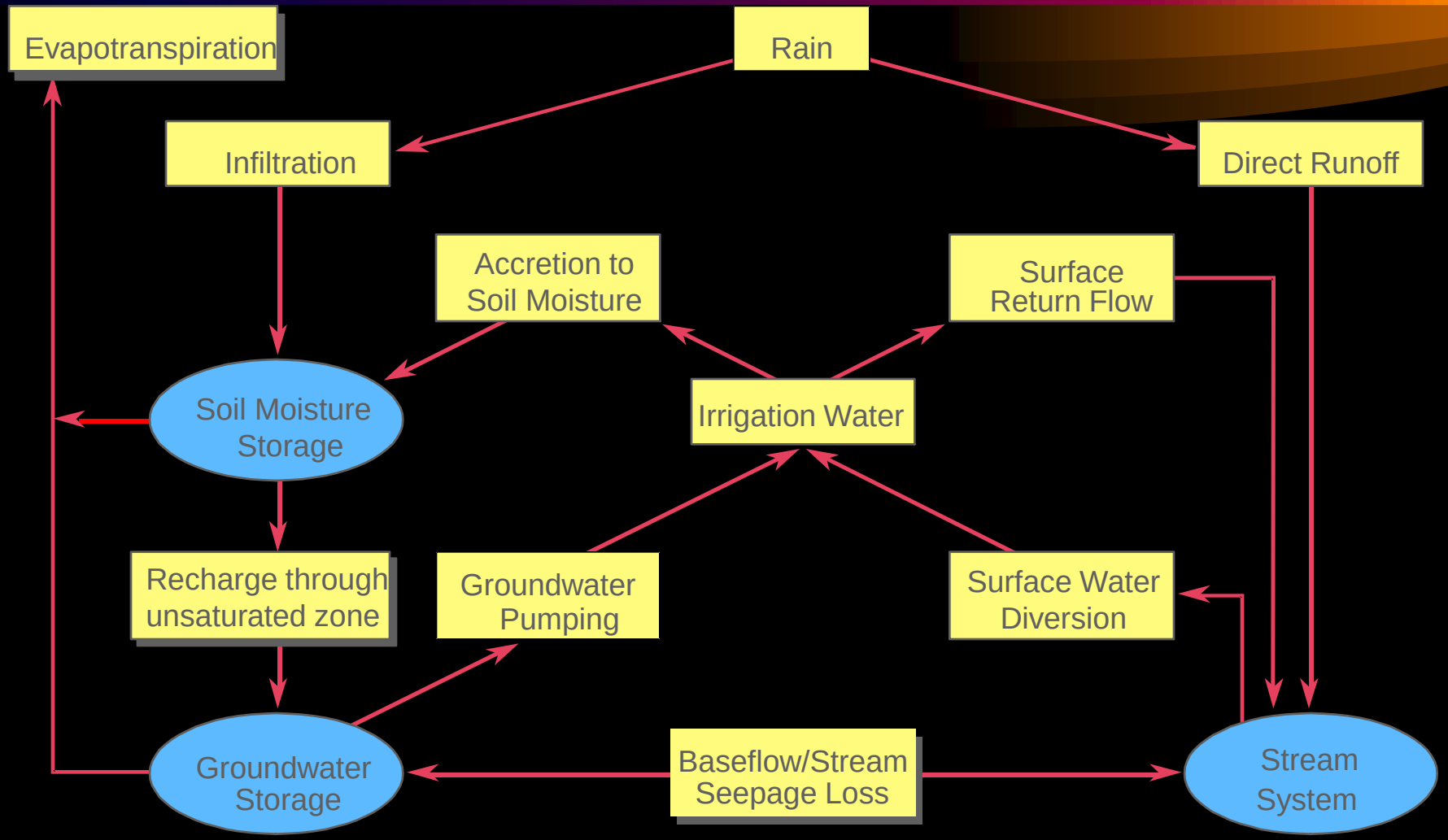
Specification	386 Machine	Modern Laptop
Processing Speed	12-40 MHz	2.0 GHz - 5.0 GHz
MIPS (Million Instructions Per Second)	~1-2 MIPS	100+ MIPS
Hard Drive	40 MB - 500 MB	256 GB - 2 TB
RAM	2 MB - 8 MB	8 GB - 64 GB (or more)
Battery Life	N/A (Desktop)	5-20 hours (depends on usage)
Weight	~20-30 lbs (desktop)	2-5 lbs (portable/laptop)

Cooking of IGSM Began in Sacramento in 1989

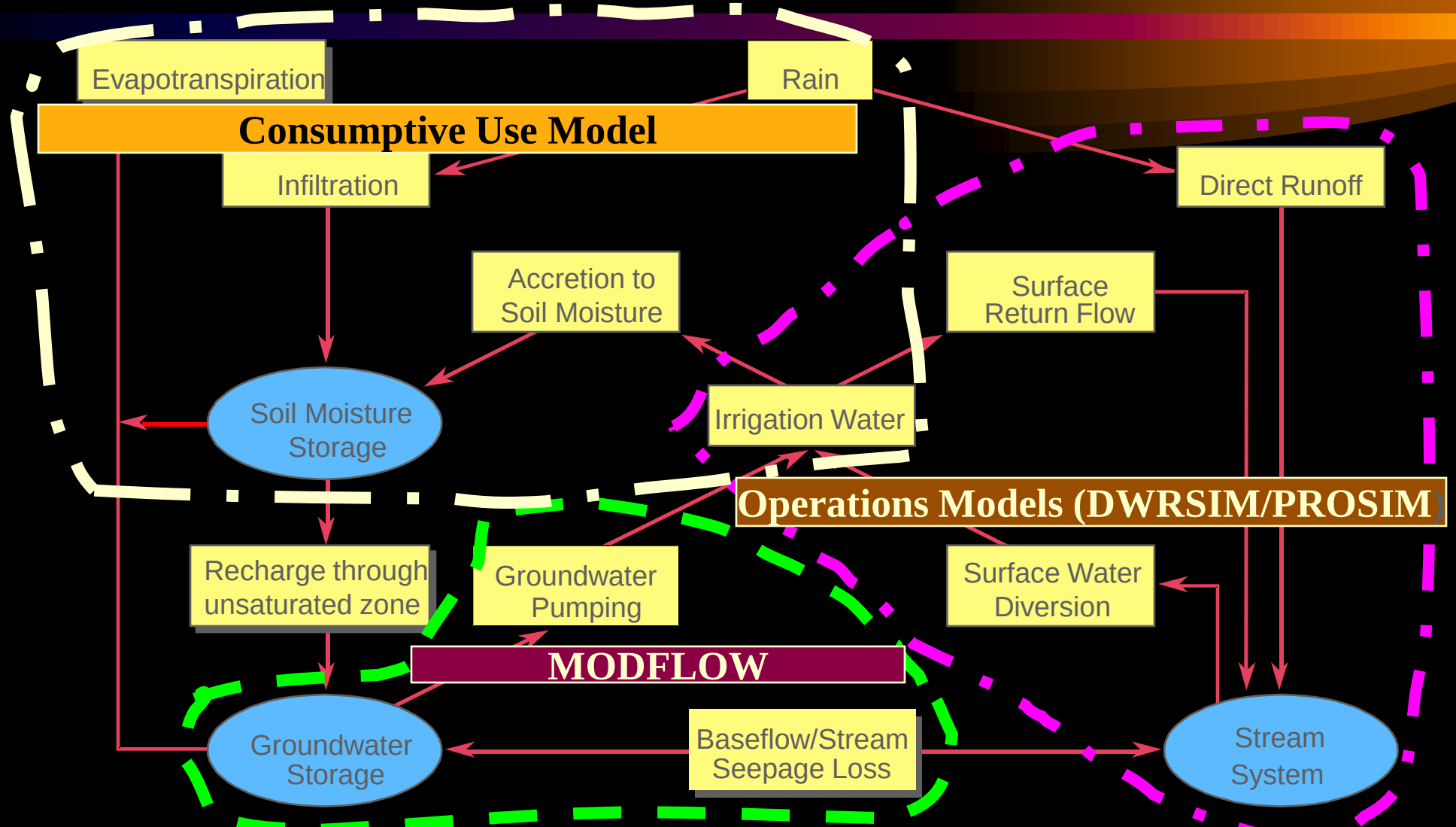


1989 September Boat Trip

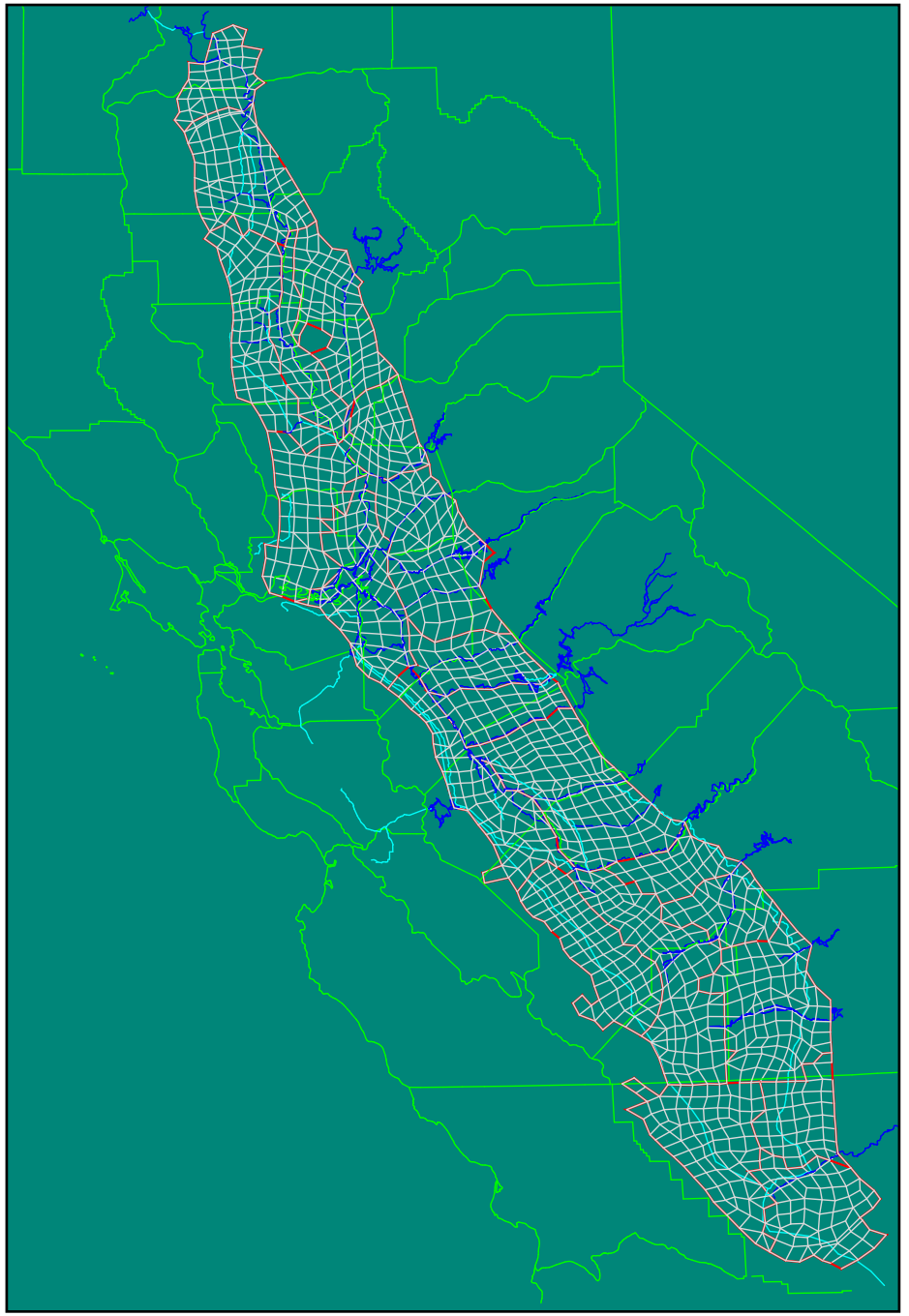
IGSM was Far Ahead of its Time
The First Comprehensive Hydrologic Model



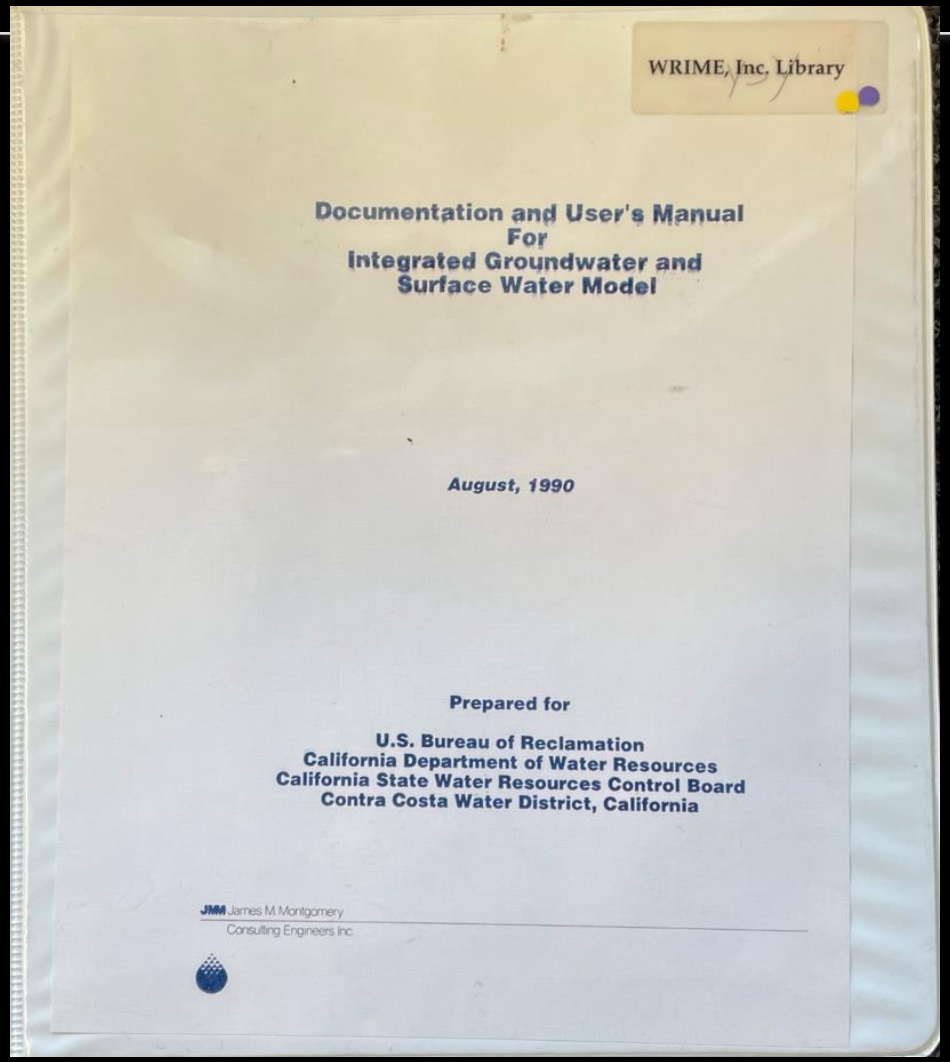
Hydrologic Components

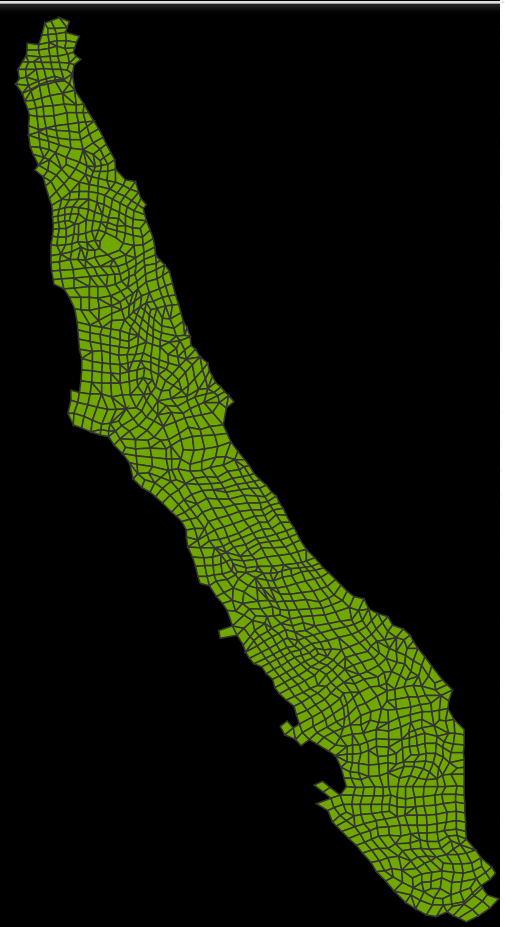


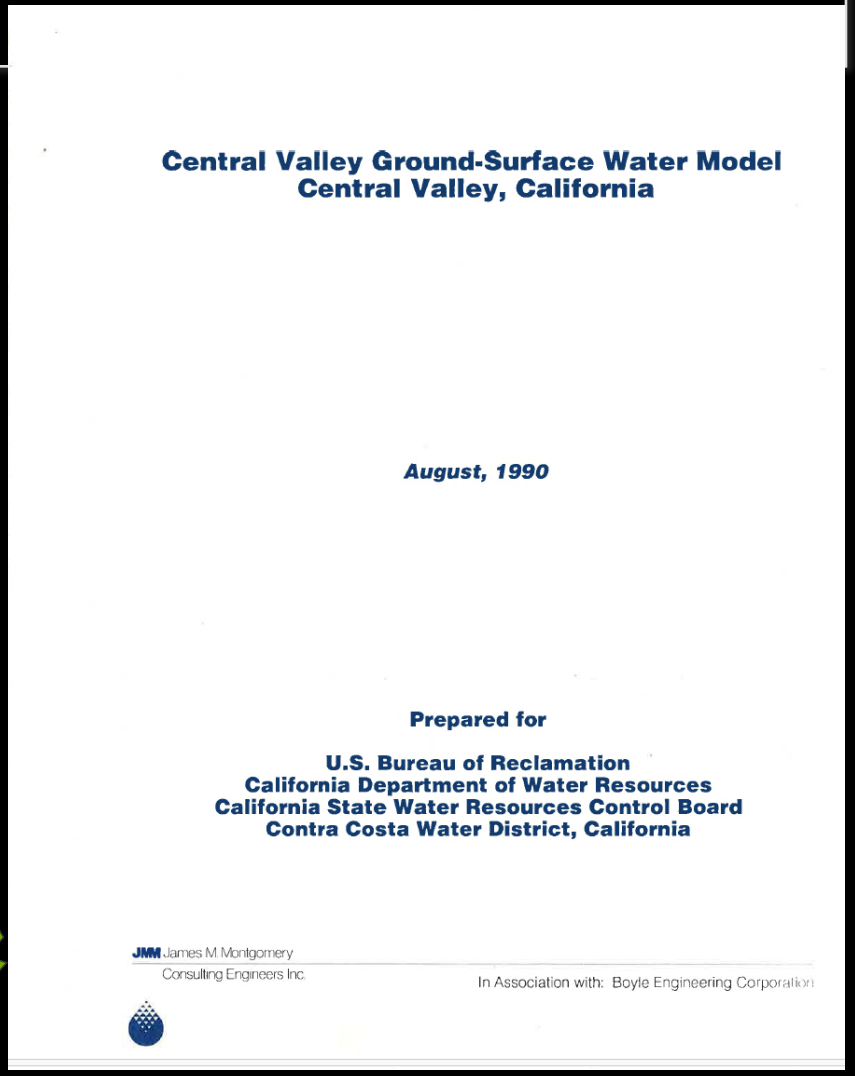
C2VSim Coarse Grid was Hand Drawn on Light Table



August 1990
IGSM was Born!



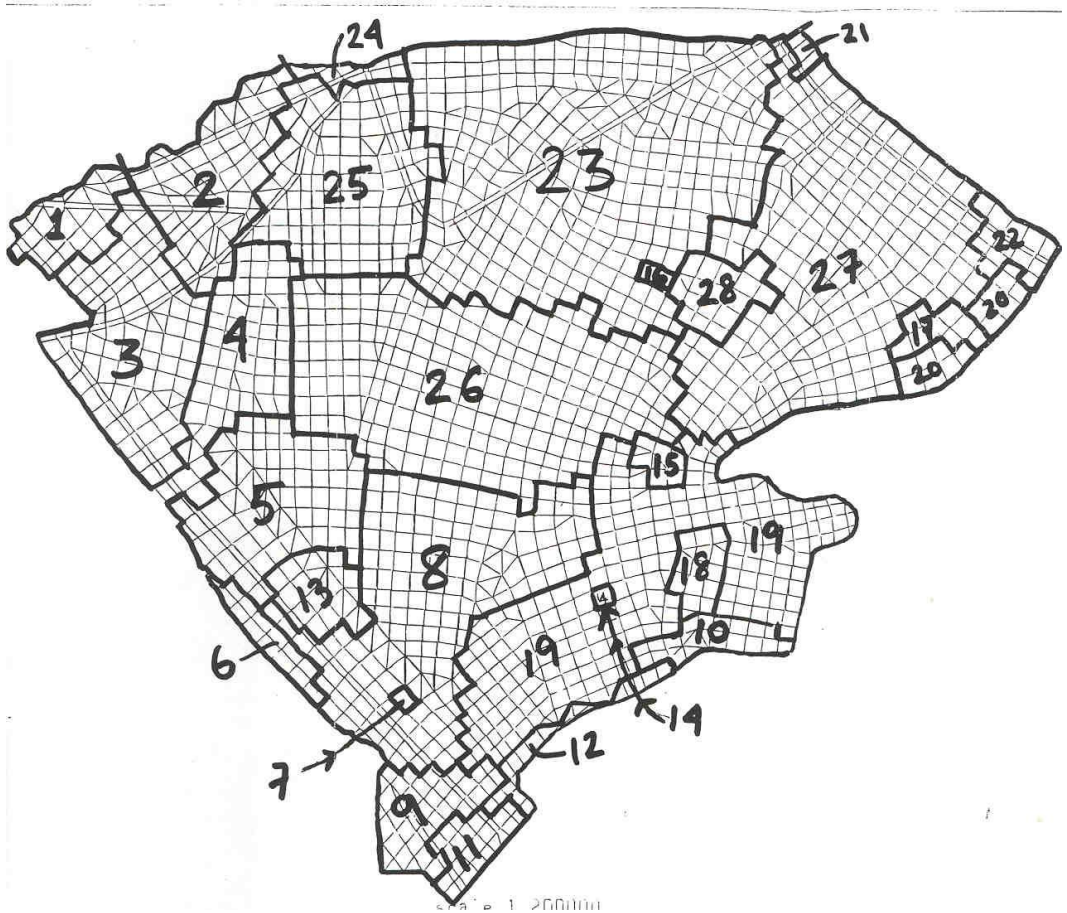




IGSM Introduced Comprehensive Water Budgeting in 1989

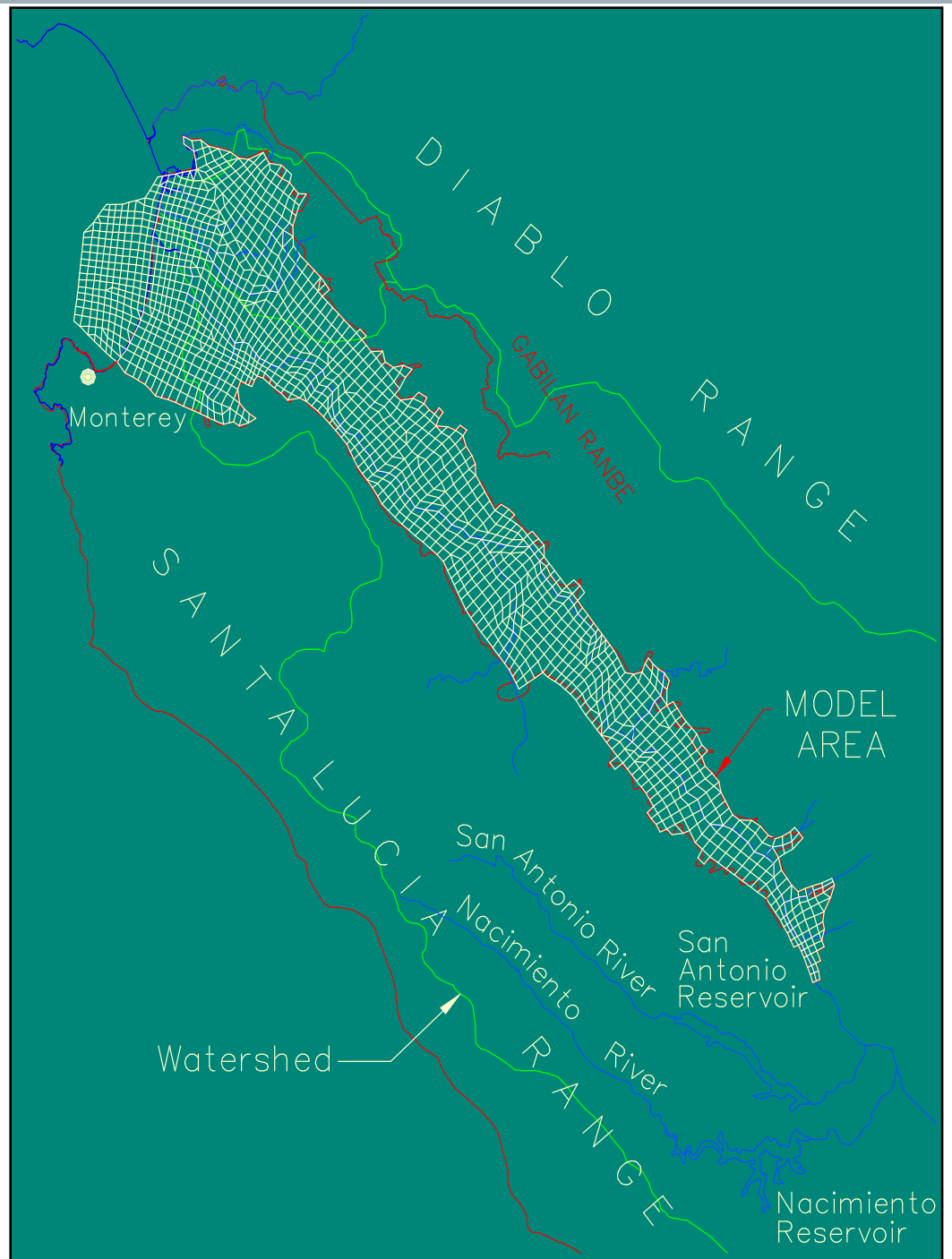
- Soil Moisture Budget
- Land and Water Use Budget
- Groundwater Budget
- Stream Budget

Chino Basin, Southern California
Water Quality Module (TDS, Nitrate, and Stream WQ)



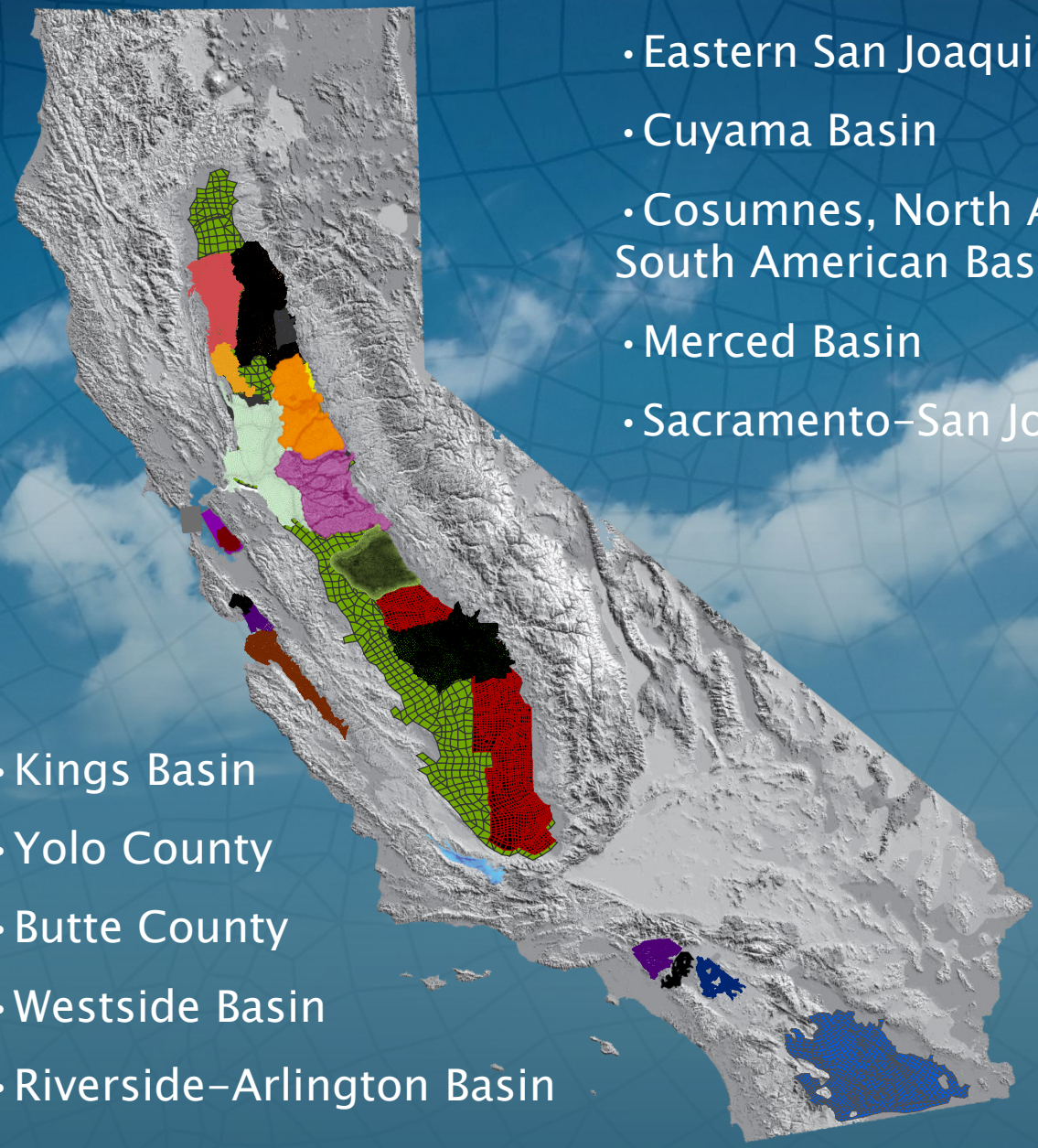
WRIME, Inc
1999

Salinas Valley Reservoir Simulation Module



- Central Valley
- Alameda County
- San Joaquin County
- Pajaro Basin
- Friant Service Area
- Sacramento County
- Salinas Valley
- San Jacinto Basin

- Chino Basin
- Imperial Valley
- North American Basin
- Soquel
- Yuba County
- Lower Colusa Basin
- Niles Cone
- Stony Creek Fan



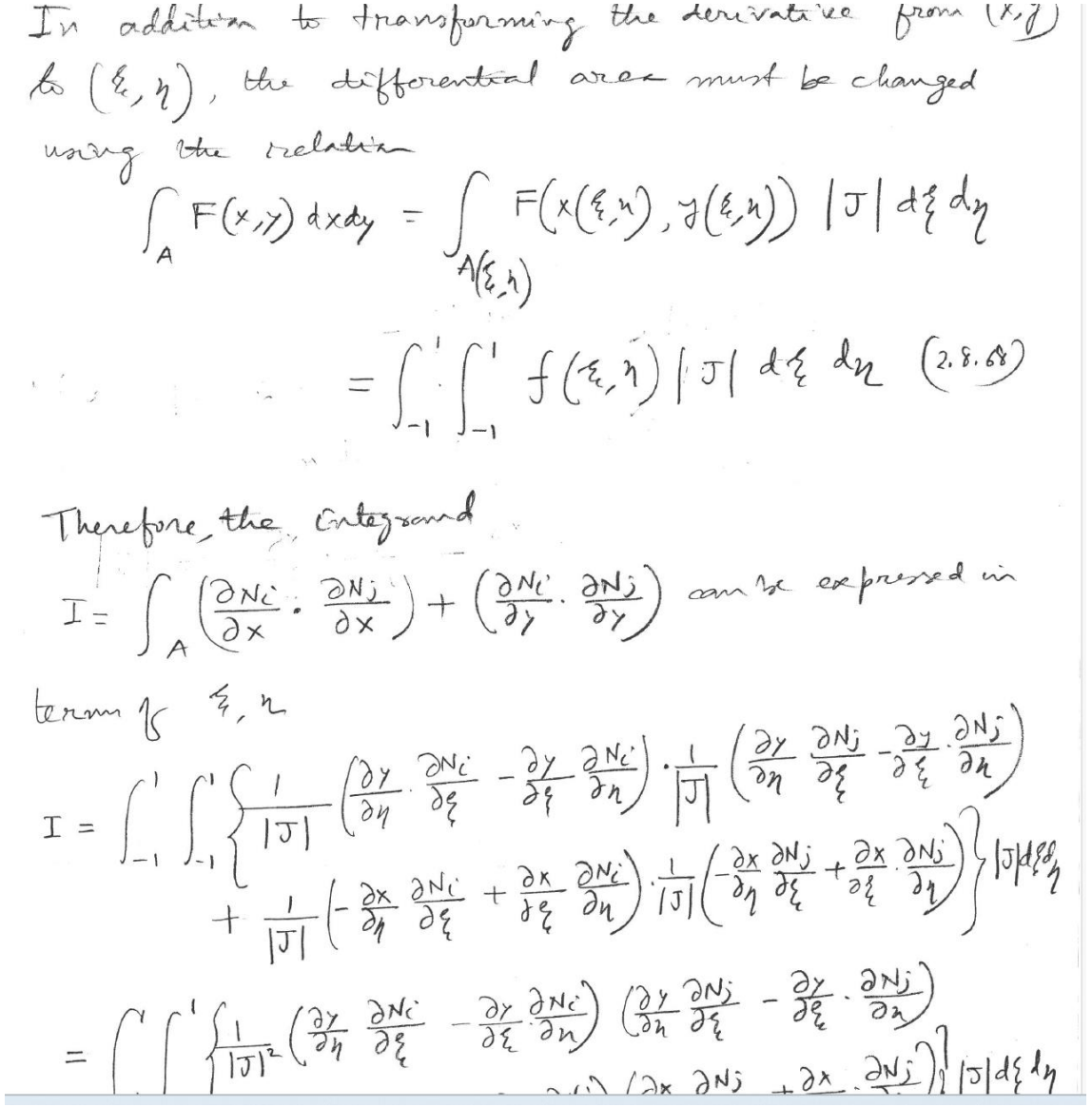
- Kings Basin
- Yolo County
- Butte County
- Westside Basin
- Riverside-Arlington Basin

- Eastern San Joaquin Basin
- Cuyama Basin
- Cosumnes, North American, South American Basins
- Merced Basin
- Sacramento-San Joaquin Delta

1990-1993 | 1994-2004 | 2005-2016 | 2000-2021

The Story Continues…

- In 2000, we handed over the IGSM code to DWR
- Provided detailed documentation
- Conducted extensive work session to explain logic and code

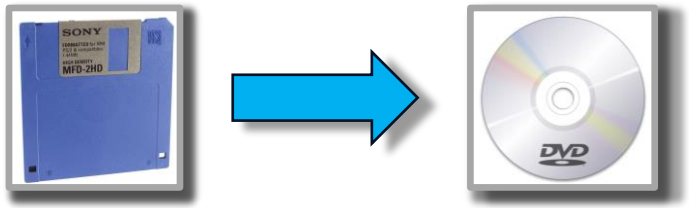


And that was the beginning of IWFM …

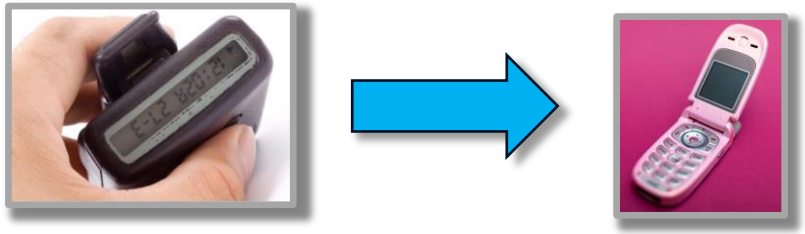
Let’s hear the story of evolution of IGSM to IWFM from Can Dogrul

Early 2000s: A Period of Transition

- From 3.5” floppy disks (1.44 MB) to DVDs (4.7 GB) for portable data storage



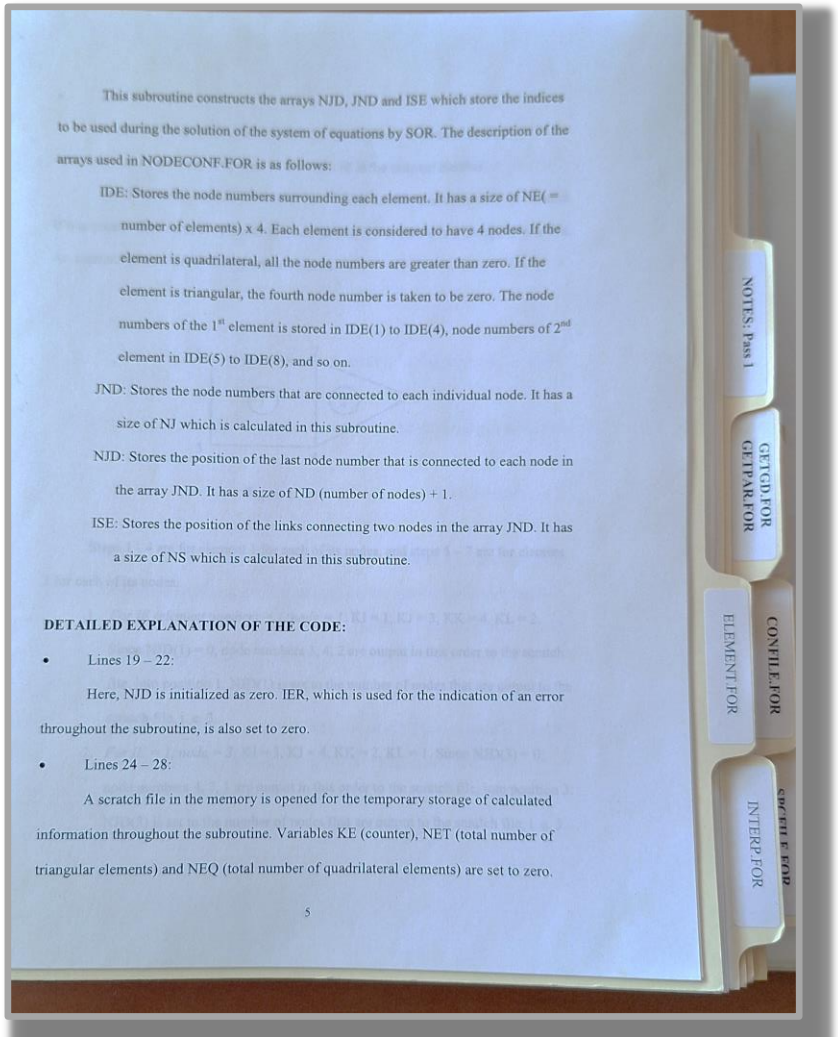
- From pagers to cell phones (flip kind)



- From command-line ARC/INFO to ArcGIS Desktop 8.0
- IGSM source code was acquired by DWR
- Can Dogrul started working at DWR

IGSM2: A Precursor to IWFM

- Spent one year to go over IGSM code line by line



This subroutine constructs the arrays NJD, JND and ISE which store the indices to be used during the solution of the system of equations by SOR. The description of the arrays used in NODECONF.FOR is as follows:

IDE: Stores the node numbers surrounding each element. It has a size of NE(= number of elements) x 4. Each element is considered to have 4 nodes. If the element is quadrilateral, all the node numbers are greater than zero. If the element is triangular, the fourth node number is taken to be zero. The node numbers of the 1st element is stored in IDE(1) to IDE(4), node numbers of 2nd element in IDE(5) to IDE(8), and so on.

JND: Stores the node numbers that are connected to each individual node. It has a size of NJ which is calculated in this subroutine.

NJD: Stores the position of the last node number that is connected to each node in the array JND. It has a size of ND (number of nodes) + 1.

ISE: Stores the position of the links connecting two nodes in the array JND. It has a size of NS which is calculated in this subroutine.

DETAILED EXPLANATION OF THE CODE:

- Lines 19 – 22:

Here, NJD is initialized as zero. IER, which is used for the indication of an error throughout the subroutine, is also set to zero.

- Lines 24 – 28:

A scratch file in the memory is opened for the temporary storage of calculated information throughout the subroutine. Variables KE (counter), NET (total number of triangular elements) and NEQ (total number of quadrilateral elements) are set to zero.

5

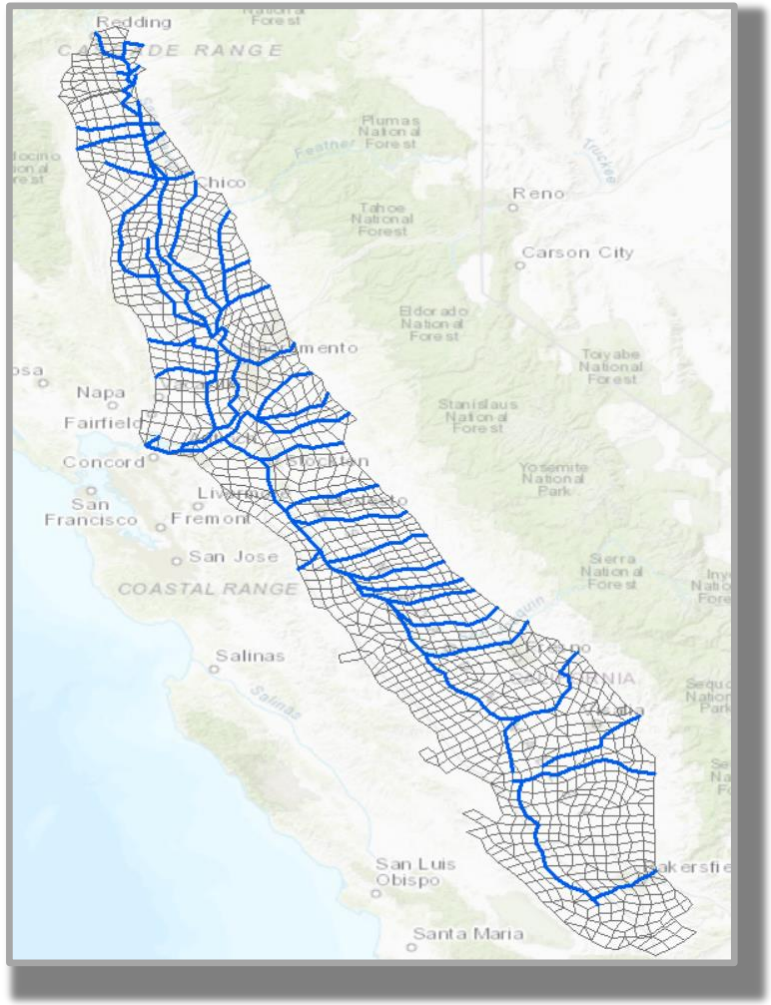
NOTES: Pass 1
GETGD.FOR GETPAR.FOR
CONFILE.FOR ELEMENT.FOR
INTERP.FOR

IGSM2: A Precursor to IWFM

- Spent one year to go over IGSM code line by line
- Initial goal was to improve simulation of stream-aquifer interaction
  - Explicit method used groundwater heads from previous timestep
  - Stream-aquifer interaction pattern was one timestep behind groundwater and stream head patterns
  - Introduced implicit method and iterative Newton-Raphson solution
  - CVGSM runtimes went from 2 minutes to 15 minutes
- Improved Budget outputs
- First public release as IGSM2 in December 2002 and workshop
- In 2005, IGSM2 was renamed “IWFM” to avoid confusion with IGSM

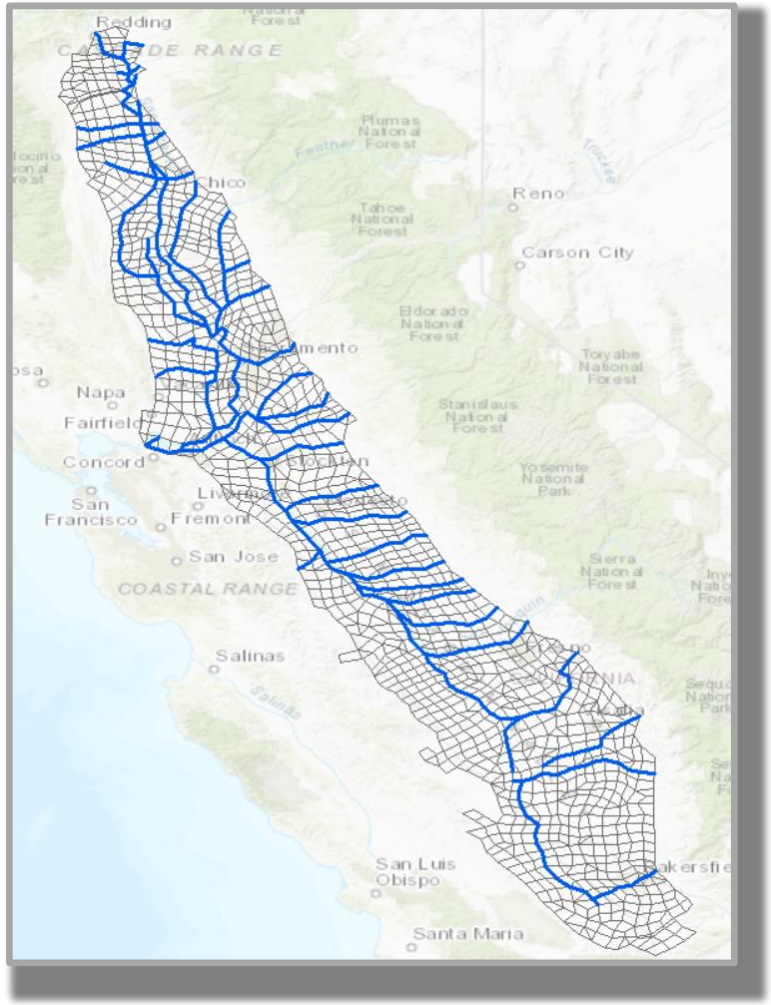
Birth of IDC and OOP Approach

- C2VSim (formerly, CVGSM) was the main reason, initially, for DWR to develop and maintain IWFM
- In 2005, groundwater and root zone components of IWFM were turned into stand-alone components to be used in CalSim



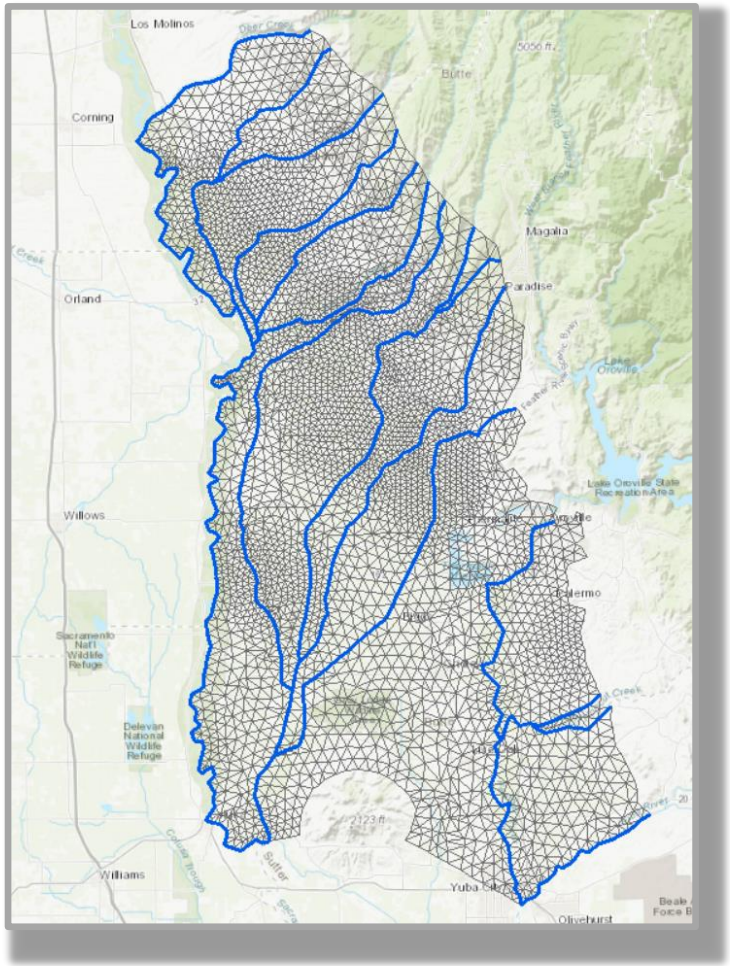
Birth of IDC and OOP Approach

- Issues faced:
  - Difficult to carve out IWFM code to turn into stand-alone components
  - IDC resulted in flashy aquifer recharge, lacked explicit rice and refuge simulations,
- Lessons learned led to
  - Start of OOP design; i.e. highly modular and reusable code development
  - IDCv4.0 (2011): explicit rice and refuge simulations, methods burrowed from FAO-56, simulation of continuous recharge, simulations at cell level



Switch to HDF5 Files

- Initially, IWFM Budget and Z-Budget files were printed to native Fortran binary files
- Butte Co. IWFM model pushed these binary files to their limit
  - 7216 grid cells
  - 9 layers
  - 16071 timesteps (daily model)
  - Binary output for each run around 100 GB
  - Post-processing was very slow
- Solution: Switched to HDF5 output format in 2015



SGMA and IWFM

- With passage of SGMA in 2014, IWFM's popularity exploded
- To support SGMA, several features introduced:
  - Ability to carve out local models from larger models
  - Ability to link neighboring IWFM models to dynamically compute boundary flow exchange (Simulation_MM)
  - Parallel processing for faster runtimes
  - IWFM API for users to interact with IWFM models and develop their own visualization/analysis tools
- Today, 70% of Central Valley GSAs use IWFM-based models (cut-out models from C2VSimFG or SVSim, or independent local models) for their GSPs

IWFM Continues to Evolve

- IWFM_OPS: Linking WRIMS, a reservoir systems operations model, with IWFM
- Improved simulation of stream-aquifer interaction; ability to differentiate between left-side interaction from right-side interaction
- Implementation of water quality modeling
- Implementation of faster solvers
- Improving parallel processing