MAR Solutions - Managed Aquifer Recharge Strategies and Actions (AG128)

Reflections on challenges in coupling spatial databases, GIS and groundwater modeling tools, promoting more effective modeling practice

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saipem

Joint International Workshop

EU FP7 MARSOL and EU HORIZON 2020 FREEWAT projects and EU EIP MAR Solutions - Managed Aquifer Recharge Strategies and Actions (AG128)

Pisa - April 21st 2015

SCOPE

Introduce the issue of data richness and complexity in groundwater (gw) management and modeling through few sample cases;

Discuss benefits and shortcomings of different strategies in coupling spatial databases, GIS and gw modeling, addressing open questions as loose vs. tight coupling, and data-centered information systems;

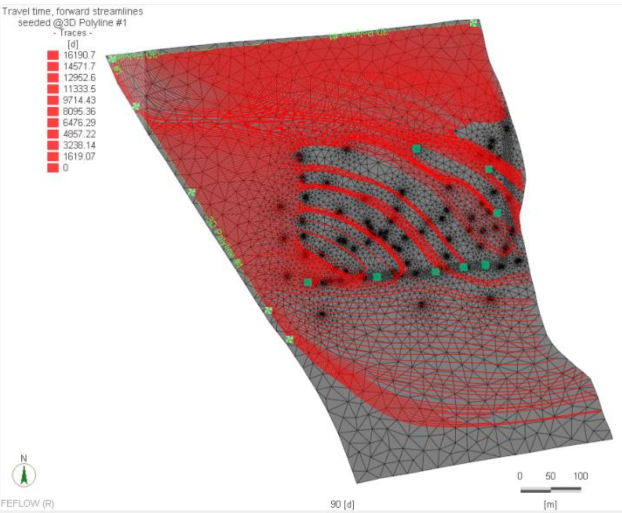
Introduce mature spatio-temporal data management issues through:

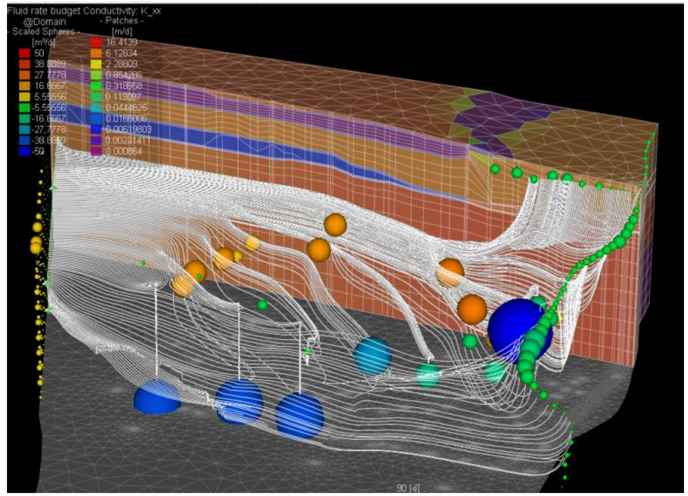
- Proprietary ESRI geodatabase architecture and ArcHydro/gwHydro data models;
- Native spatial databases using OS (Open Source) PostgreSQL/PostGIS.

Discuss two sample coupling case studies:

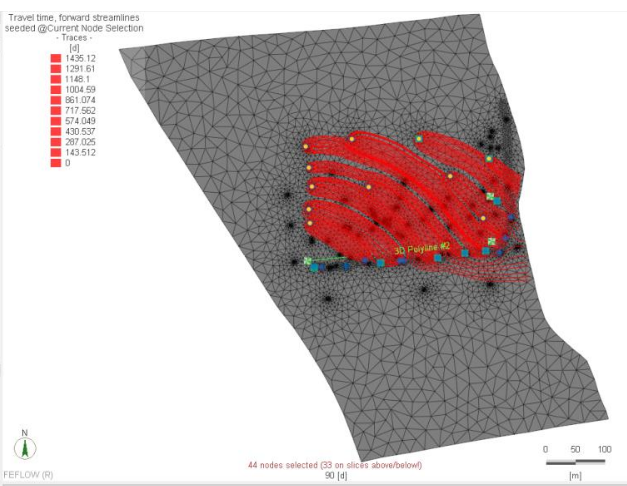
- Feflow-ArcGIS: embedding groundwater modeling engine in GIS to enable ArcGIS users to design and perform scenarios simulations backed up by geodatabase contents (models, boundary conditions, surface water levels, wells discharges);
- Design of native spatial database for groundwater monitoring, PostGIS implementation and integration with GIS and groundwater modeling environments. Feflow support to native PostgreSQL/PostGIS or Oracle spatial databases, towards more effective information systems.

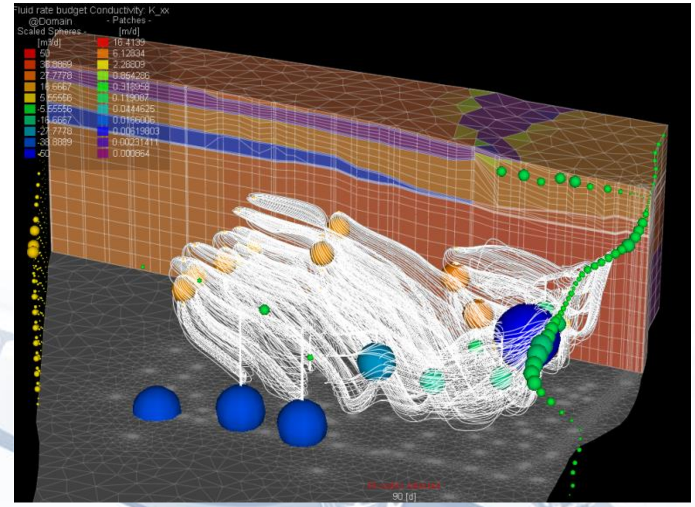
3D FLOW MODEL TO ASSESS CONTAMINATED GROUNDWATER FLOW CONTAINMENT





Streamtraces from upstream top aquifer





Streamtraces from reinjection wells

Input data:

Hydrological and hydrogeological properties;

Wells screening geometry;

Wells discharge;

Recharge at wells;

Hydrochemical data.

Modeling set up:

2D/3D mesh;

Boundary conditions (inflow, rivers, channels).

Computed data:

Piezometric heads;

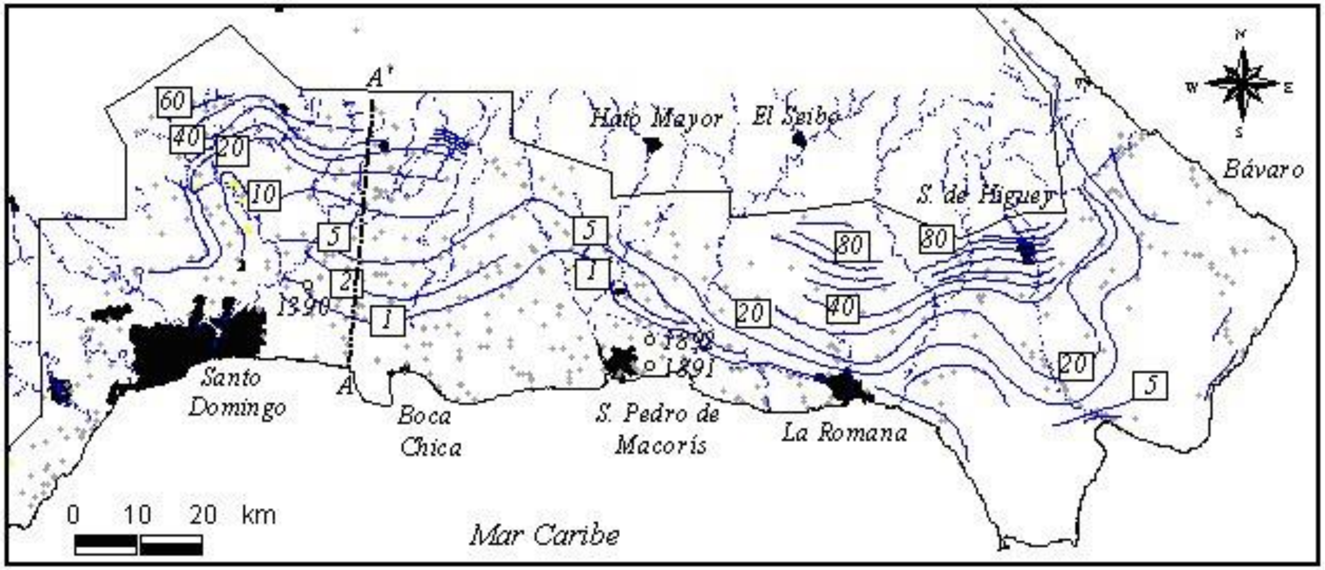
Streamtraces;

Concentrations.

And most of data being variable in space and time

....!

SALT WATER INTRUSION AND LOCAL UPCONING PHENOMENA RELATED TO GROUNDWATER SUPPLY ALONG COASTAL AREAS

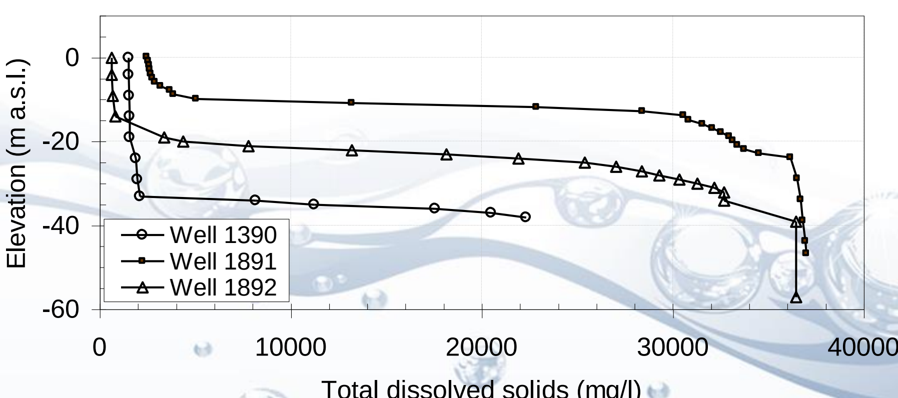


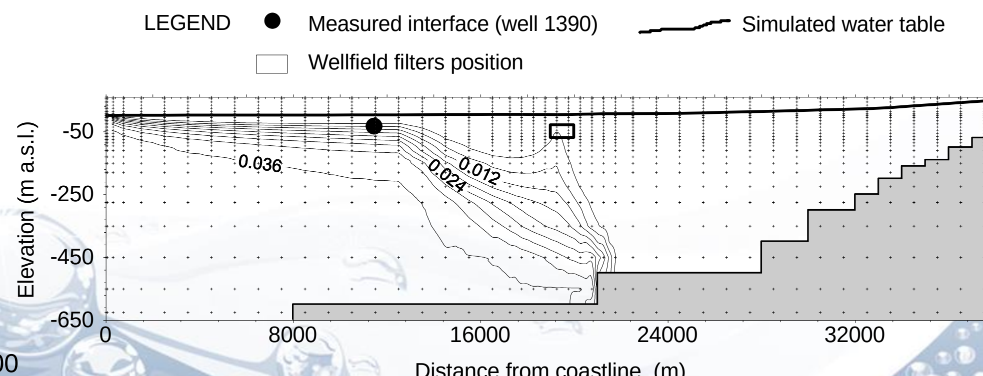
20 *Mean piezometry (m a.s.l.)* *Small circles indicate wells stored to the project relational database*

Salt water intrusion: *1390 o* *Example control points (and reference code)* *A-A' section trace*

EU funded project focused on water master plan in southern part of Dominican Republic, 1997-2000

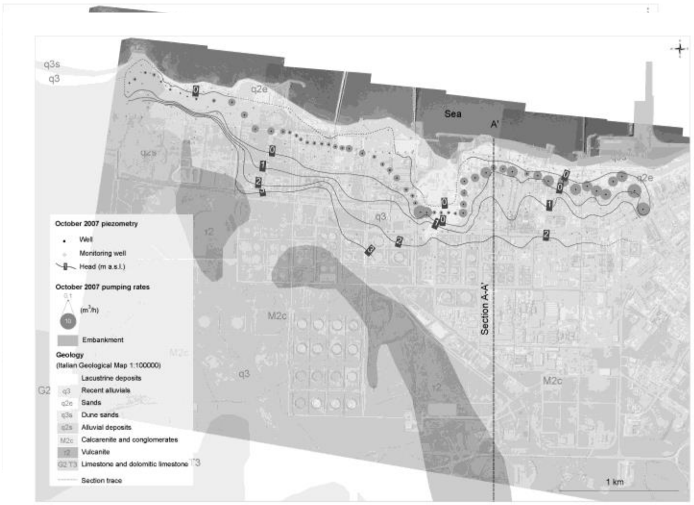
Salt water intrusion modeling with Tough2 along vertical sections transversal to sea coast in a highly permeable limestone. Salinization already affects Santo Domingo wells field located about 20 kms inland.

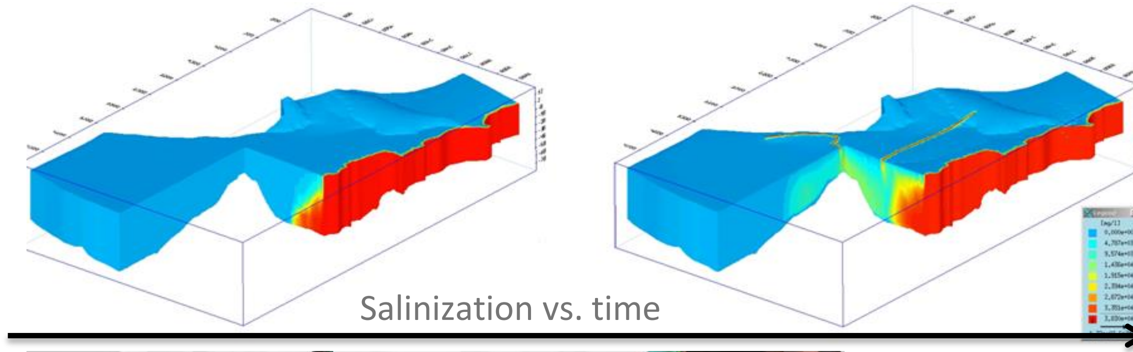




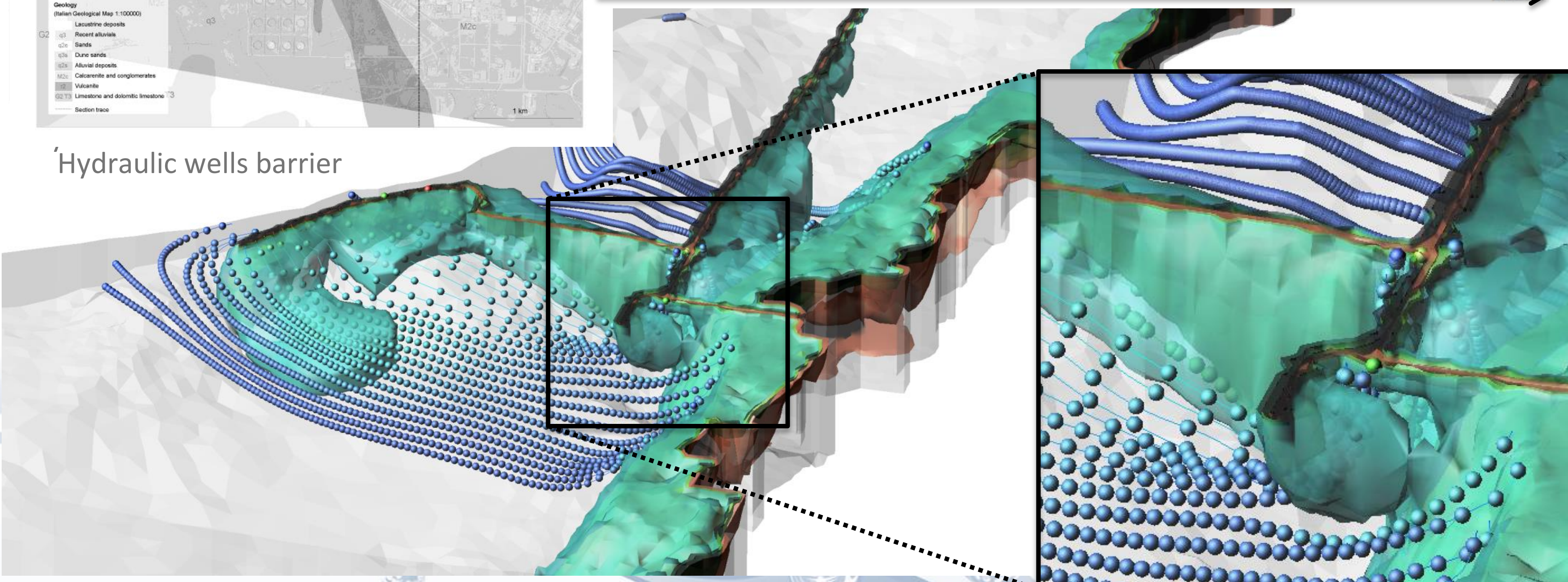
Adamés et al. (2002)

SIMULATION OF SALT WATER INTRUSION DUE TO OVERPUMPING AT A COASTAL WELLS HYDRAULIC BARRIER





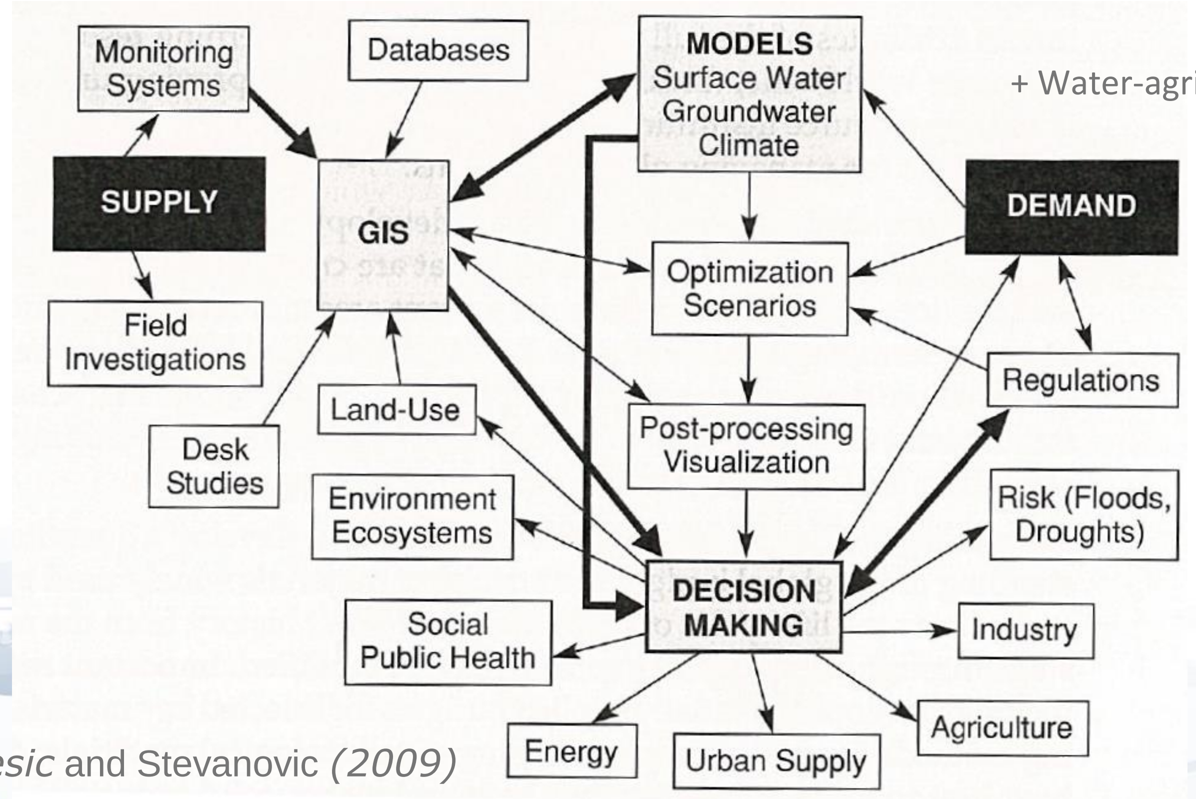
Hydraulic wells barrier



Crestaz et al., 2009, 2012

COMPLEX TOOLS INTERLINKING IN SPATIAL DECISION SUPPORT SYSTEMs (SDSSs) FOR SUPPLY vs. DEMAND ANALYSIS

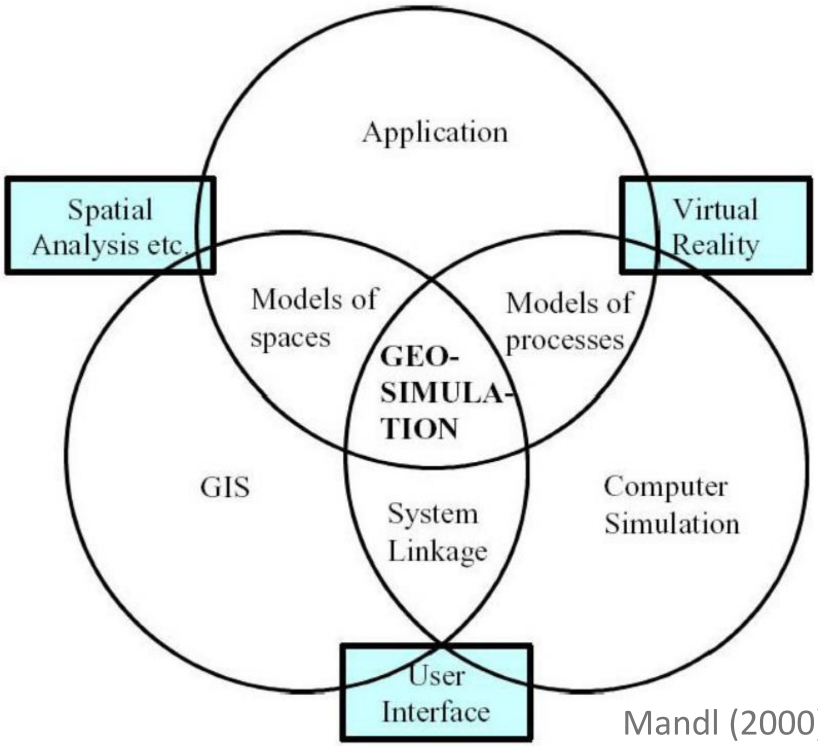
Spatio-temporal data, both observed and computed after numerical simulations, are key components of any SDSS. Mature data management strategies are highly beneficial to effectiveness of the decision making process, improved quality, better allocation of responsibilities …



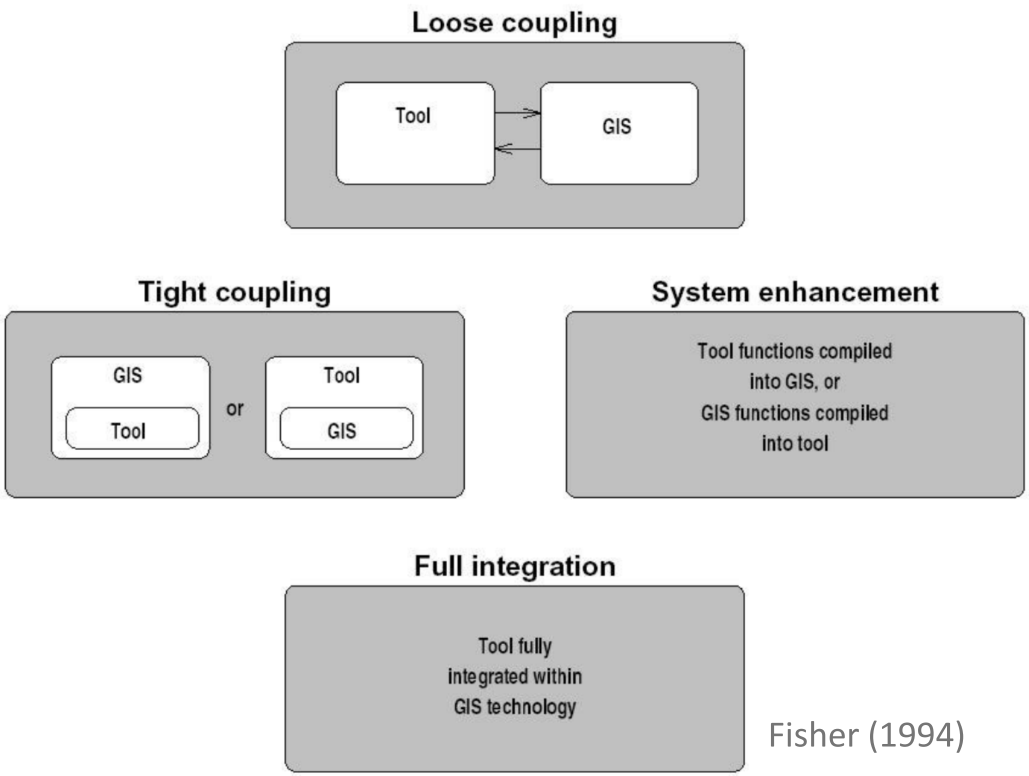
+ Water-agriculture-energy nexus

Kresic and Stevanovic *(2009)*

GEO-SIMULATION AND COUPLING STRATEGIES



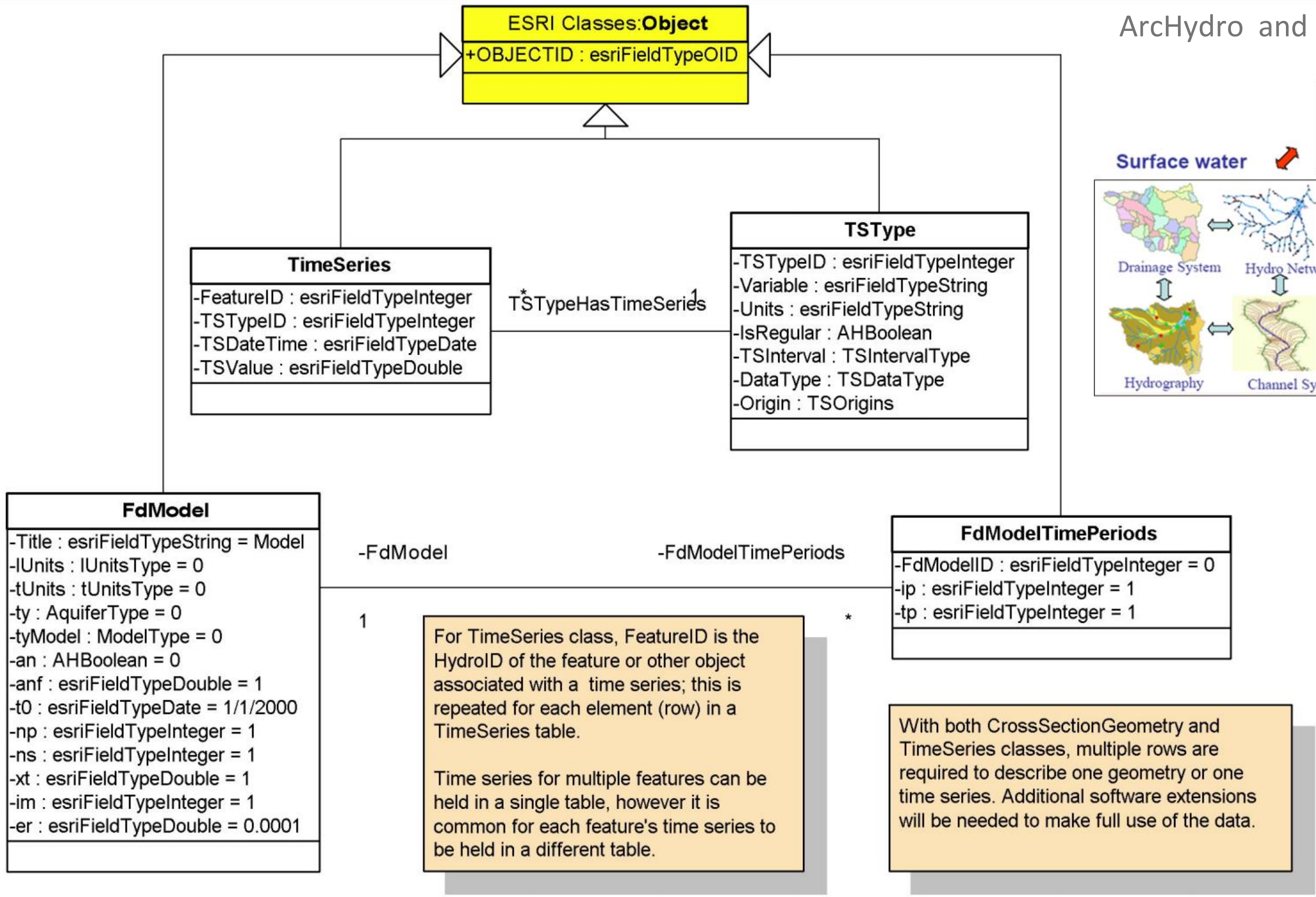
Mandl (2000)



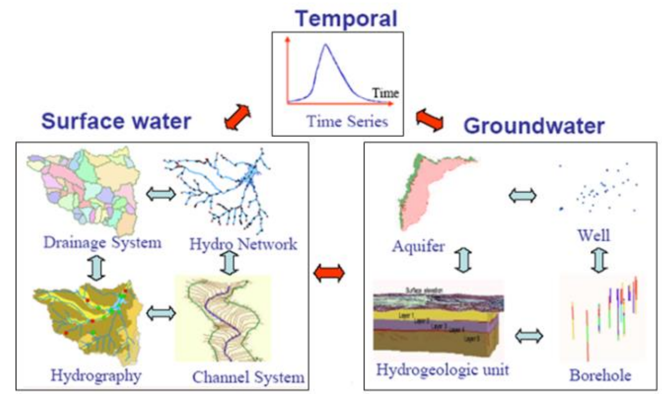
Fisher (1994)

- GIS and gw models interchanging data through shape files
- Native spatial databases as common data provider backbone for GIS, spatial statistics, advanced geovisualization and gw modeling
- Gw modelling environments as advanced dedicated 3D temporal GIS

ESRI GEODATABASE: EXTENDING ARCHYDRO DATA MODEL TO COPE WITH FINITE DIFFERENCE NUMERICAL MODELS



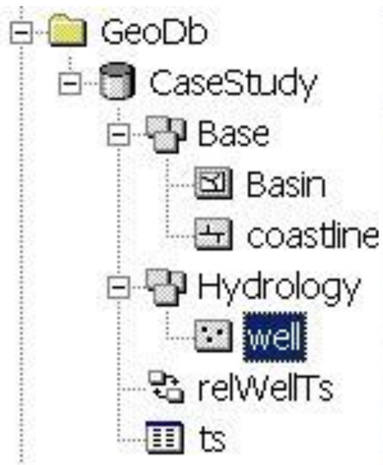
ArcHydro and gw Hydro data models

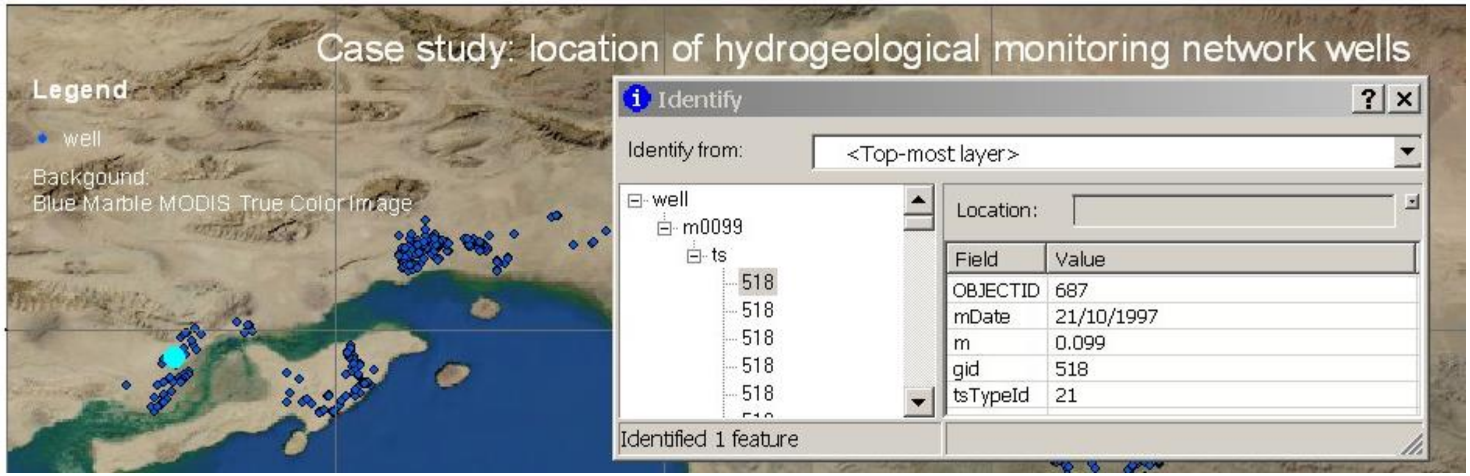


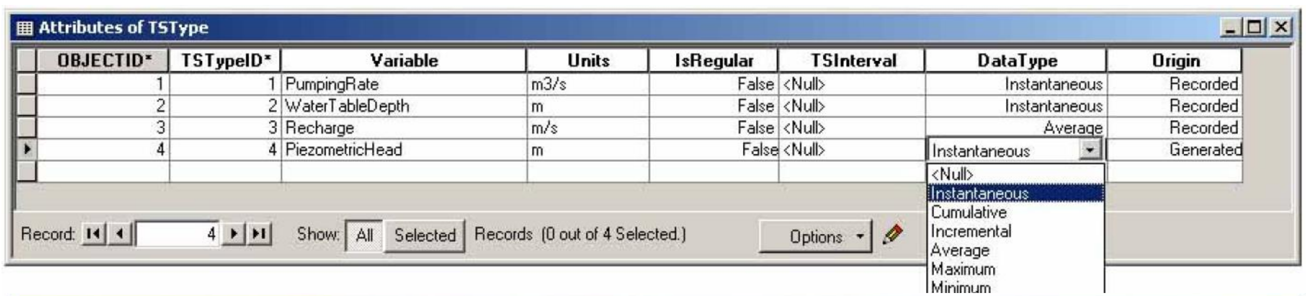
Extending ArcHydro database model to manage gw finite difference numerical models

Maidment (2002), Crestaz (2003), Strassberg et al. (2011)

ESRI GEODATABASE: SPATIO-TEMPORAL DATA QUERYING AND EDITING BASED ON ARCHYDRO DATA MODEL

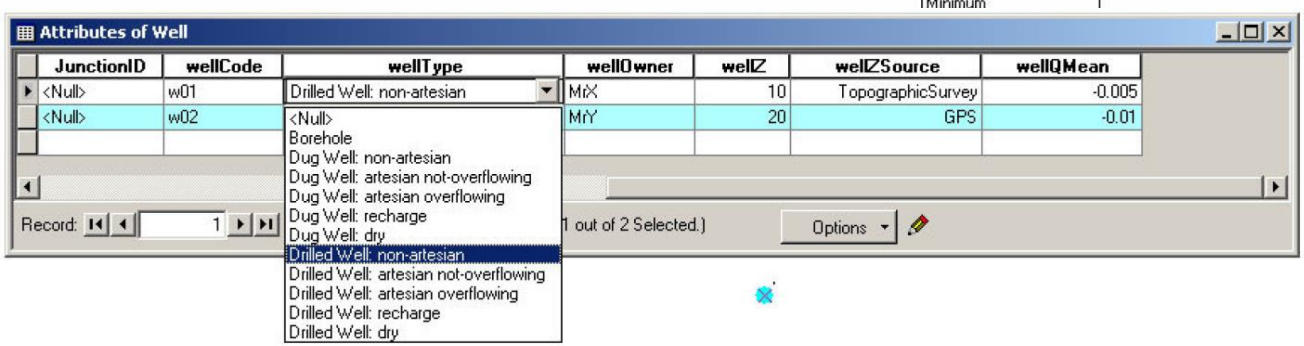






Attributes of TSType

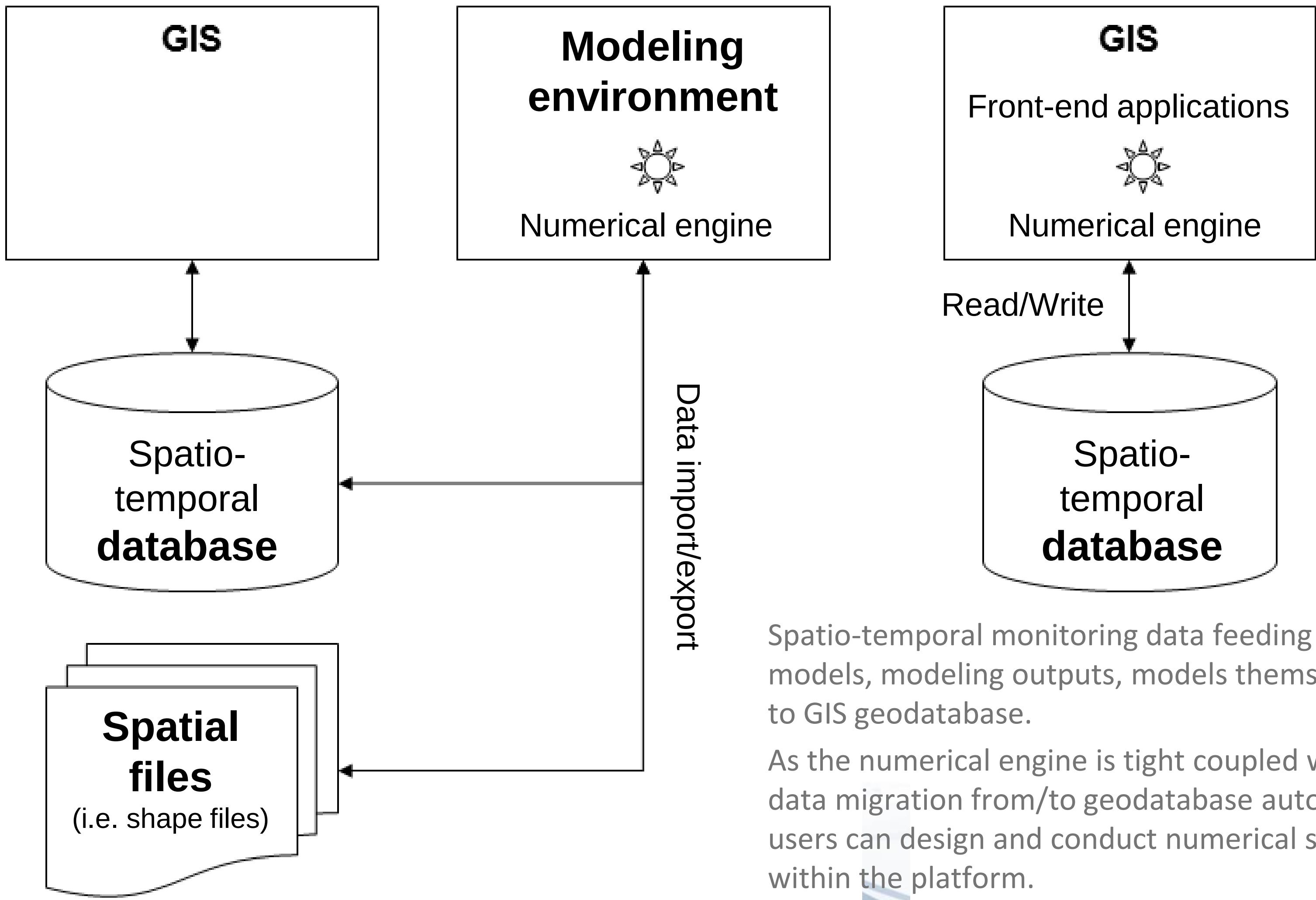
OBJECTID*	TSTypeID*	Variable	Units	IsRegular	TSInterval	DataType	Origin
1	1	PumpingRate	m3/s	False	<Null>	Instantaneous	Recorded
2	2	WaterTableDepth	m	False	<Null>	Instantaneous	Recorded
3	3	Recharge	m/s	False	<Null>	Average	Recorded
4	4	PiezometricHead	m	False	<Null>	Instantaneous	Generated



Attributes of Well

JunctionID	wellCode	wellType	wellOwner	wellZ	wellZSource	wellQMean
<Null>	w01	Drilled Well: non-artesian	MrX	10	TopographicSurvey	-0.005
<Null>	w02		MrY	20	GPS	-0.01

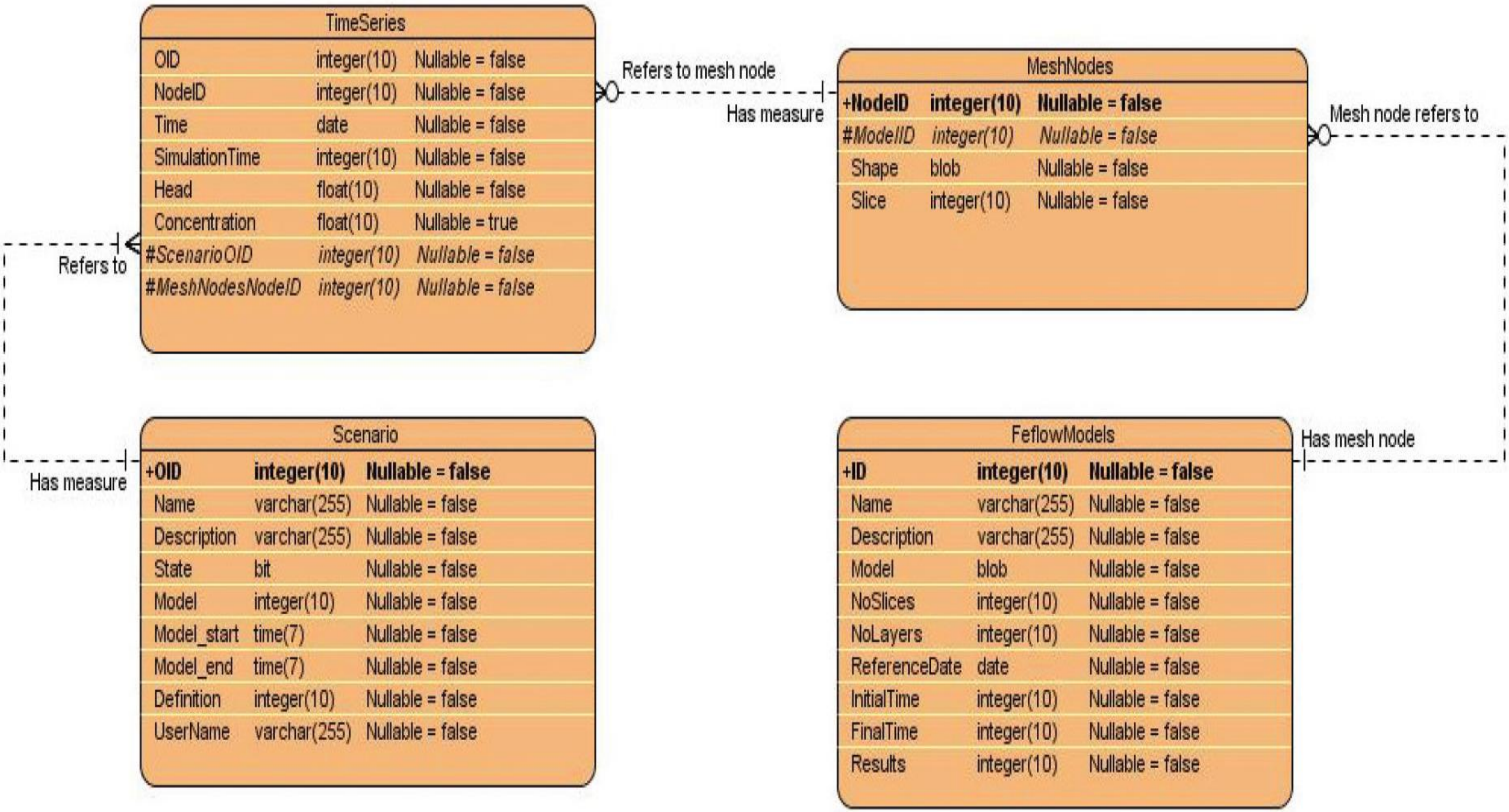
FEFLOW-ARCGIS CASE STUDY: GENERAL CONCEPT AND NUMERICAL ENGINE FULLY-EMBEDDED IN GIS



Spatio-temporal monitoring data feeding groundwater models, modeling outputs, models themselves can be stored to GIS geodatabase.

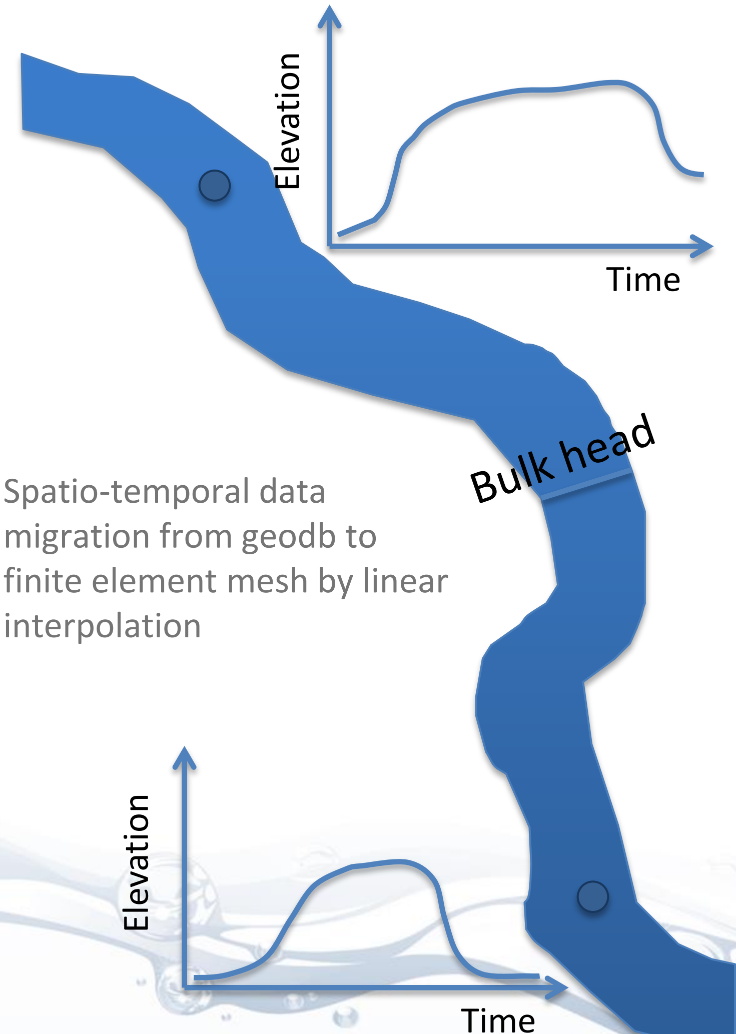
As the numerical engine is tight coupled within the GIS and data migration from/to geodatabase automatically performed, users can design and conduct numerical simulations from within the platform.

FEFLOW-ARCGIS CASE STUDY: SPATIO-TEMPORAL GEODB DESIGN TO MANAGE FEFLOW SIMULATION DATA

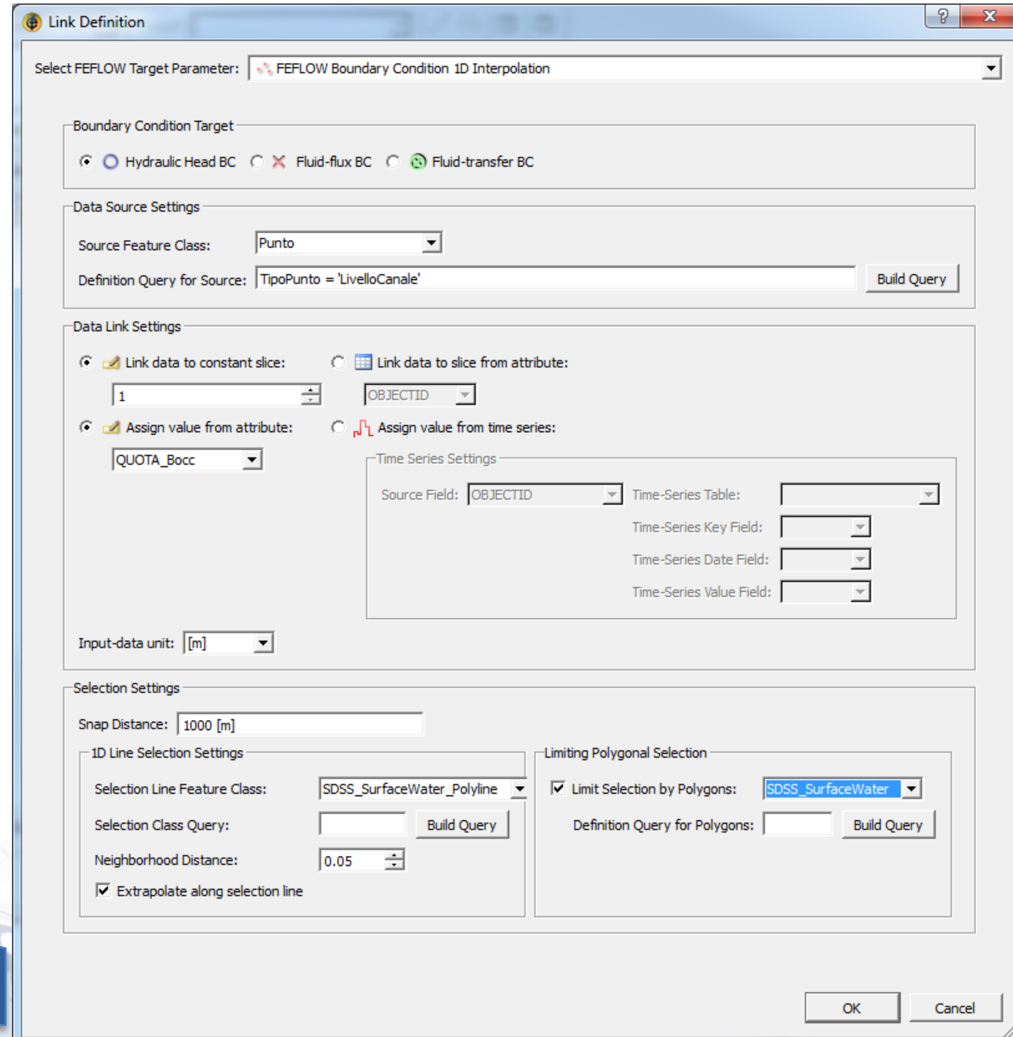


Crestaz et al. (2012b)

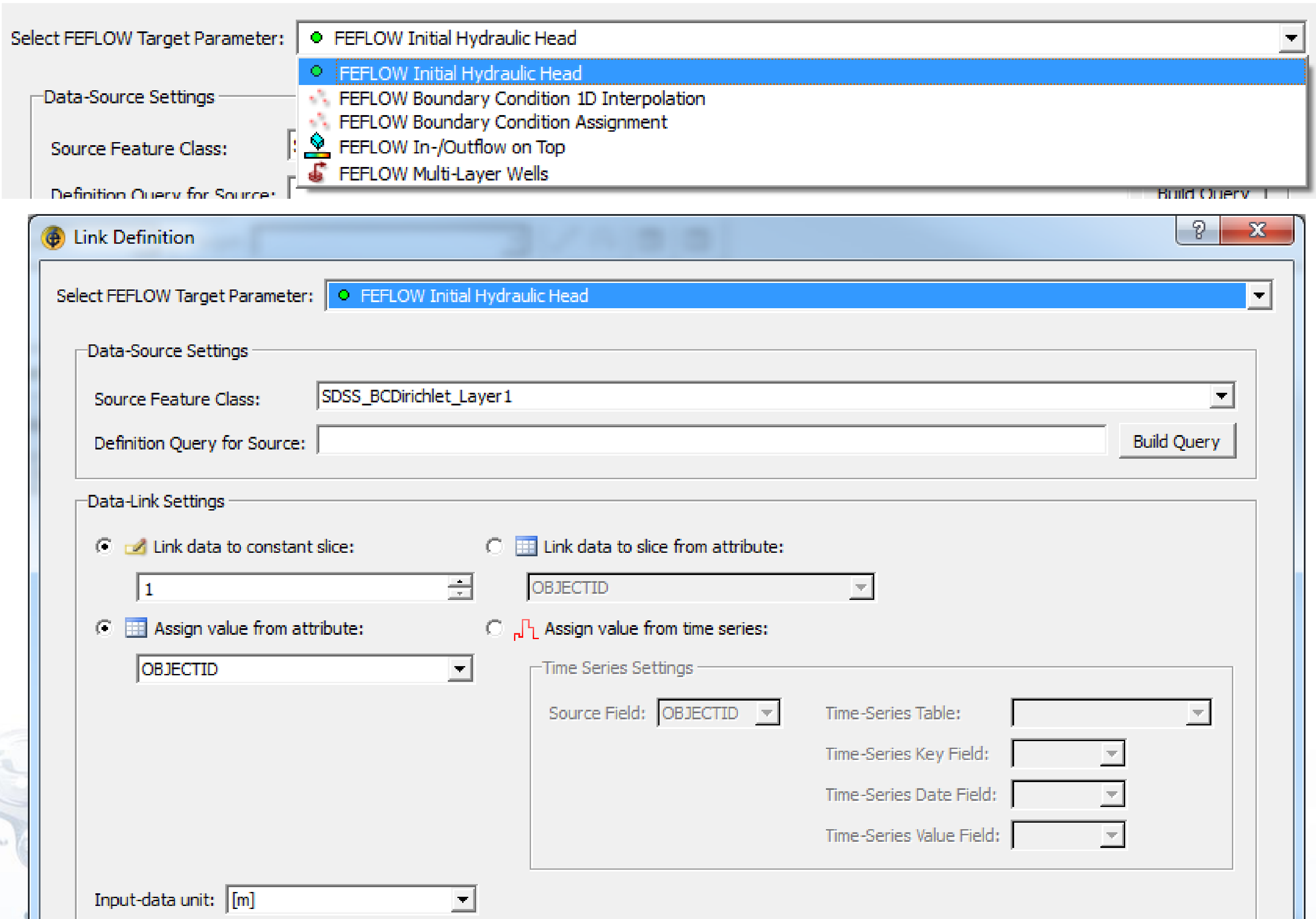
FEFLOW-ARCGIS CASE STUDY: CONCEPTS AND GUI TO MANAGE 1-D INTERPOLATION ALONG BOUNDARY CONDITIONS



Spatio-temporal data migration from geodb to finite element mesh by linear interpolation



FEFLOW-ARCGIS CASE STUDY: GUI FOR SETTING UP BOUNDARY CONDITIONS BASED ON GEODB CONTENTS

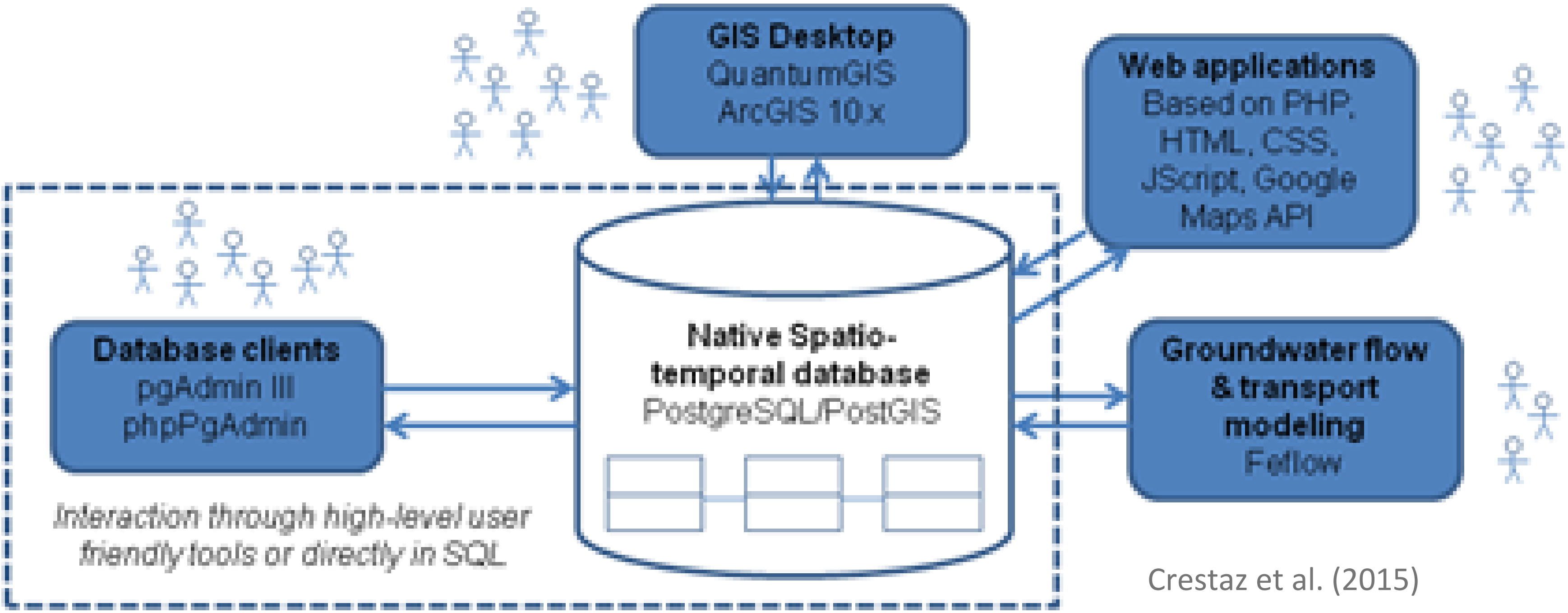


NATIVE SPATIAL DATABASES: DEFINITION AND KEY FEATURES

Spatial data model	Support to new spatial data types, as vector SDO_GEOMETRY in Oracle and geometry/geography in PostGIS. Raster data support in Oracle Spatial and PostGIS 2.x (Kothuri et al., 2004; Obe and Hsu, 2011)
Spatial data loading features	Spatial data loading utilities enable easy import of external spatial data sources, as shape files loaders for Oracle (SDO2SHP) and built-in PgAdmin III facilities for PostgreSQL/PostGIS
Spatial indexing	Traditional binary trees indexes, not effective on multi-dimensional spatial data, are complemented by spatial indexes, as Rtree family for vector and quadtree for raster data (Worboys, 1995; Worboys and Duckman, 2004)
Spatial query language	SQL, the traditional declarative RDBMS database lingua franca, is extended, according to OGC and ISO, to provide additional capabilities to create, process, query and analyze spatial data (Obe and Hsu, 2011)

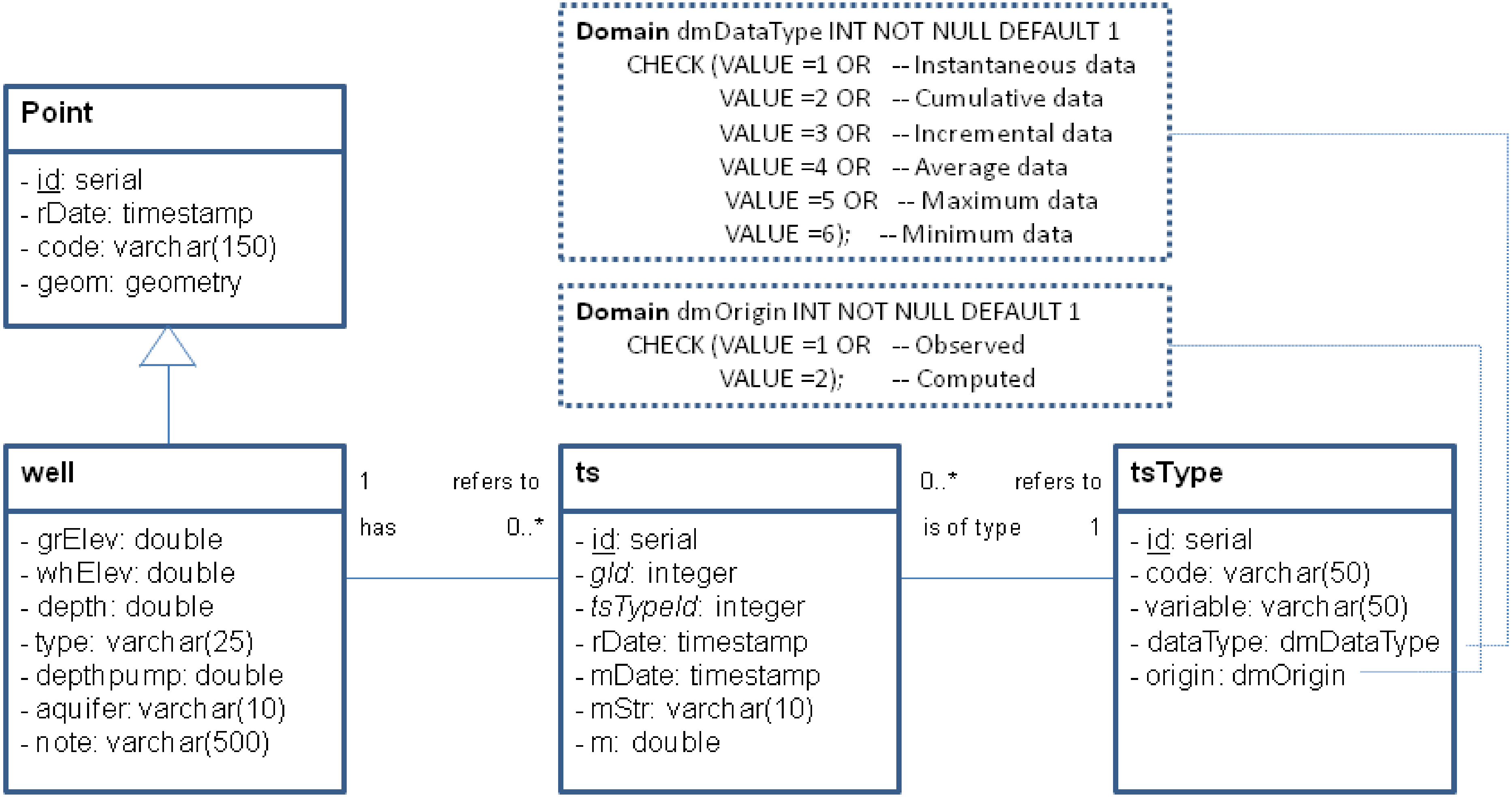
NATIVE SPATIO-TEMPORAL DATABASE-CENTERED ARCHITECTURES

ORACLE (XE up to Enterprise+Spatial Oracle) and PostgreSQL/PostGIS are prominent examples of native spatial databases. They can be accessed through dedicated clients (as pgAdmin III), GIS tools, or embedded in web applications. Read/write access from/to gw modeling environments can be implemented to develop enterprise data-centered architectures



Crestaz et al. (2015)

SPATIO-TEMPORAL DATABASE DESIGN



Maidment R., 2002; Crestaz E., 2011; Crestaz E. et al., 2015

SPATIO-TEMPORAL DB IMPLEMENTATION IN POSTGIS: GEOMETRY ATTRIBUTES AND CONSTRAINTS CREATION

SQL (Standard Query Language) is declarative and easy to learn and use. Spatial data management adds some complexity, but not too much ... Benefits are worth the effort!

Look at monitoring point table creation and constraints enforcement (spatial reference system and geometry primitive)

```
CREATE TABLE ems.point(
  id integer PRIMARY KEY DEFAULT NEXTVAL('seq_geom'),
  rDate timestamp NOT NULL DEFAULT LOCALTIMESTAMP,
  code varchar(150) NOT NULL,
  geom geometry NOT NULL);

ALTER TABLE ems.point ADD CONSTRAINT enforce_srid_geom
CHECK (st_srid(geom) = 4326);

ALTER TABLE ems.point ADD CONSTRAINT geom_point_check
  CHECK (geometrytype(geom) = 'POINT');0
```

SPATIO-TEMPORAL DB IMPLEMENTATION IN POSTGIS: INHERITED TABLE CREATION AND SPATIAL INDEXING

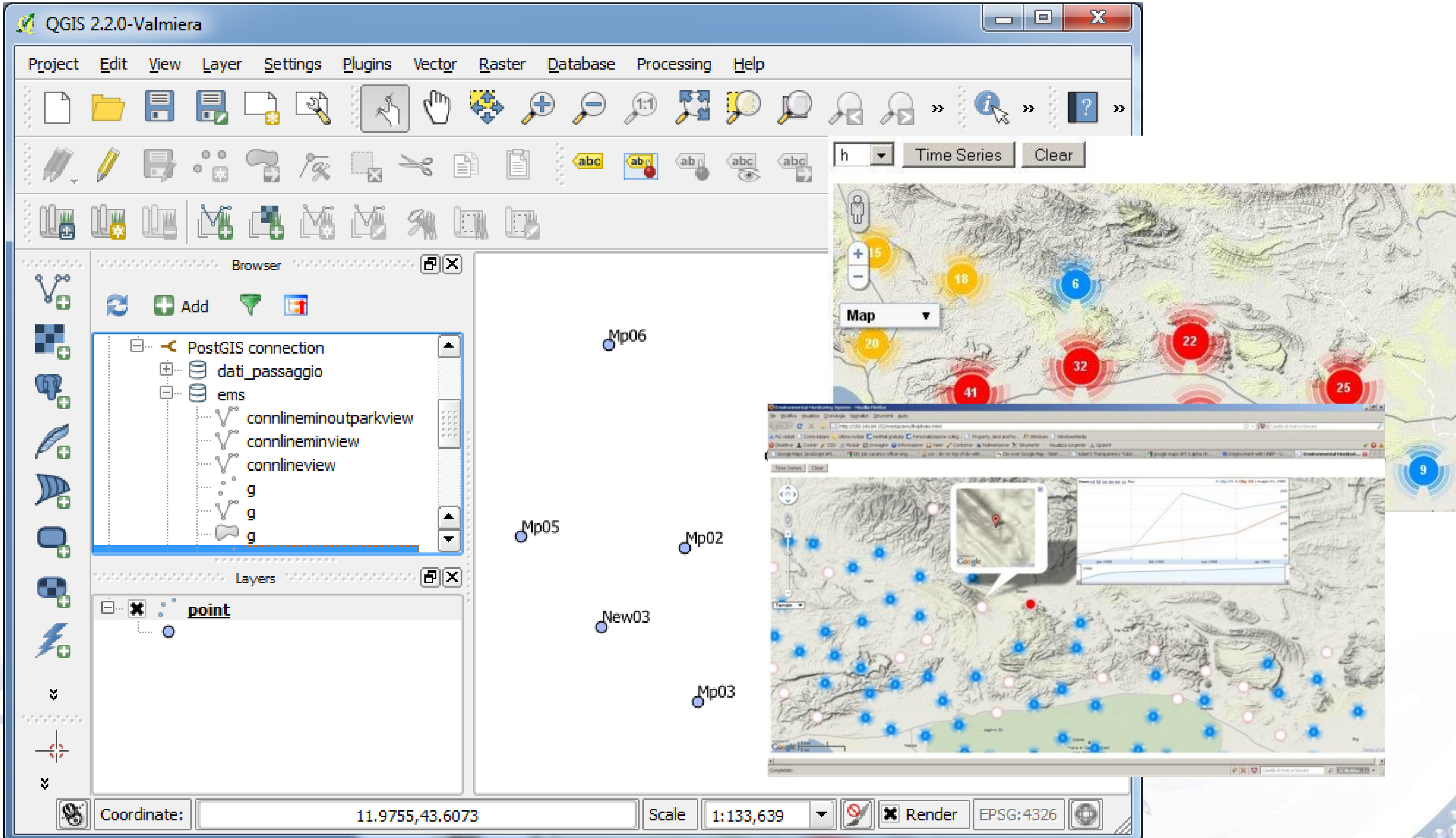
OO (Object Oriented) inheritance concept implemented at monitoring well table creation and spatial indexing on geometry field

```
CREATE TABLE ems.well (
  grElev double precision,          -- Ground elevation
  whElev double precision,          -- Well head elevation
  depth double precision,           -- Well depth
  type varchar(25) NOT NULL,        -- Type (w,p,t)
  depthpump double precision,       -- Pump depth
  aquifer varchar(10),              -- Aquifer code
  note varchar(500),                -- Notes
  CONSTRAINT pk_point PRIMARY KEY (id),
  CONSTRAINT type_well_check CHECK (type IN ('w','p','t'))
) INHERITS (ems.point);

CREATE INDEX idx_point_geom ON ems.point USING GIST(geom);

CREATE INDEX idx_well_geom ON ems.well USING GIST(geom);
```

SPATIO-TEMPORAL DB IMPLEMENTATION IN POSTGIS: VIEWS CREATION

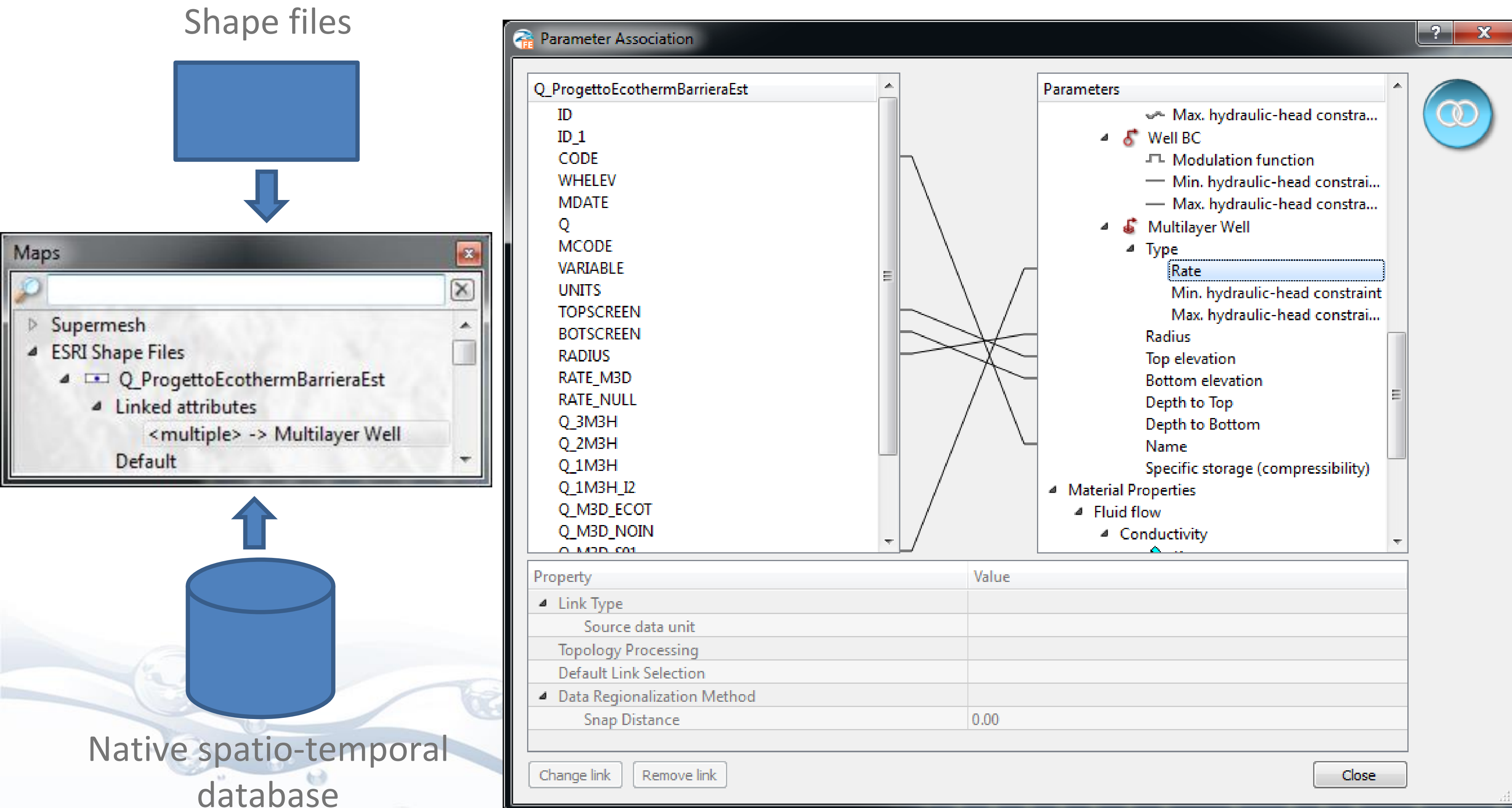
```
CREATE OR REPLACE VIEW pgaleria.view_h AS (
  SELECT ts.id,       -- Unique ID (to be used in GIS)
         w.code,      -- Well code
         w.whelev,    -- Well head elevation
         w.geom,      -- Well location
         ts.mDate,    -- Measurement date
         ts.m,        -- Measurement (depth from Ground, m)
         tsType.code as mCode,    -- Measurement code
         tsType.variable,         -- Extended description
         tsType.units,            -- Measurement units
         w.whelev-ts.m as h       -- Computed head (m asl)
  FROM pgaleria.well w,
       pgaleria.ts ts,
       pgaleria.tsType tsType
  WHERE w.id = ts.gid AND                -- Table relationship
        ts.tstypeid = tsType.id AND      -- Table relationship
        tsType.code = 'DfG')             -- Measure type
```

SPATIO-TEMPORAL POSTGIS DB: ACCESS DATA SOURCE FROM DIFFERENT GIS AND WEB APPLICATIONS



Crestaz (2011), Crestaz et al. (2011)

DHI-WASY FEFLOW: MAPS AS A DATA SOURCE



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THANKS FOR THE ATTENTION