

Coupling Diverse Models

Case Study of Baltimore-Washington Region

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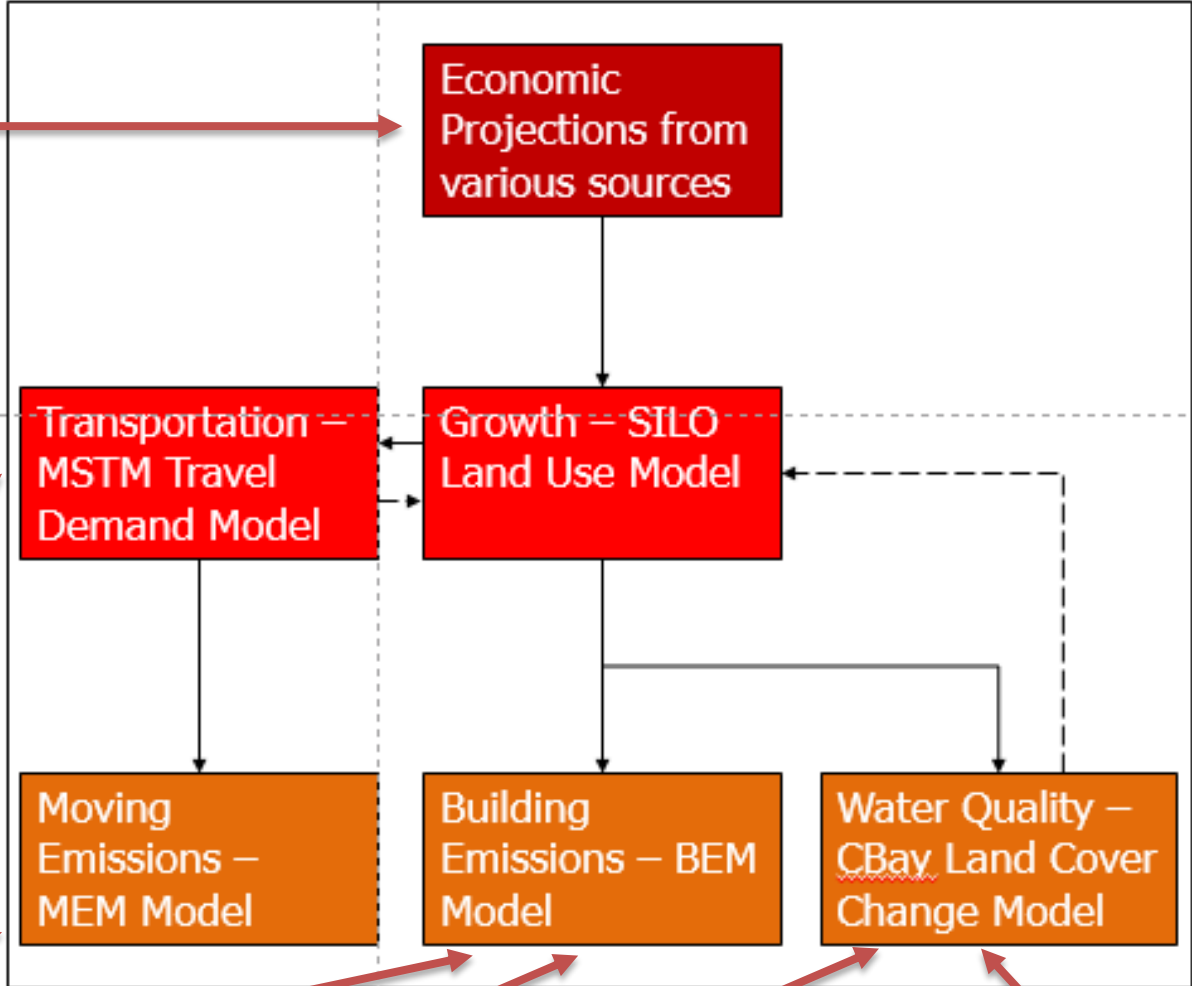


Modelling Area

- Chesapeake Bay is the largest estuary in North America stretching across 165,000 sq. km.
- The length of the coastline is longer than the entire US West Coast.
- The Bay's land-to-water ratio (14:1) is the largest in the world; thus land use has a big impact on the Bay's health
- As the host to the US capital and several large metropolitan areas the region is unique in terms of the competing interests among agriculture, land use change, urbanisation and transportation.



Model Elements



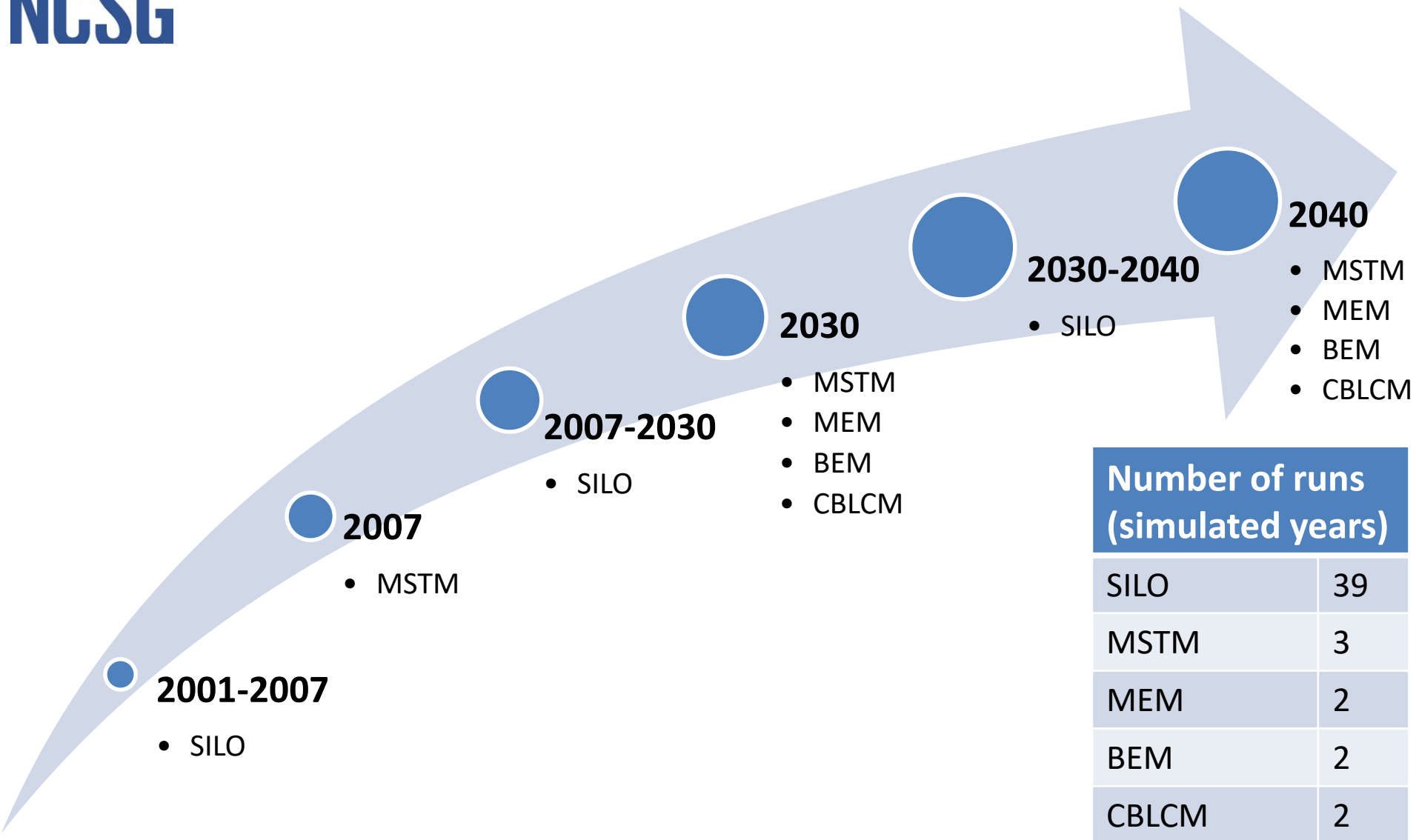
Model Characteristics



Model	Environment	Operation System	Developer/ Licensing	Number of runs	Time per run *	Overall Runtime
MSTM	CUBE	Windows	Scripts: Open source CUBE: CitiLabs	3	3 hour (16 hour)	9 hour
SILO	Java	Multi-platform	Open source	39	9 min	6 hour
MEM	CUBE	Windows	EPA (MOVES) / CitiLabs	2	30 min	1 hour
BEM	R	Multi-platform	Open source	2	30 min	1 hour
CBLCM	C / C++	CentOS Windows	USGS	2	3 hour	6 hour

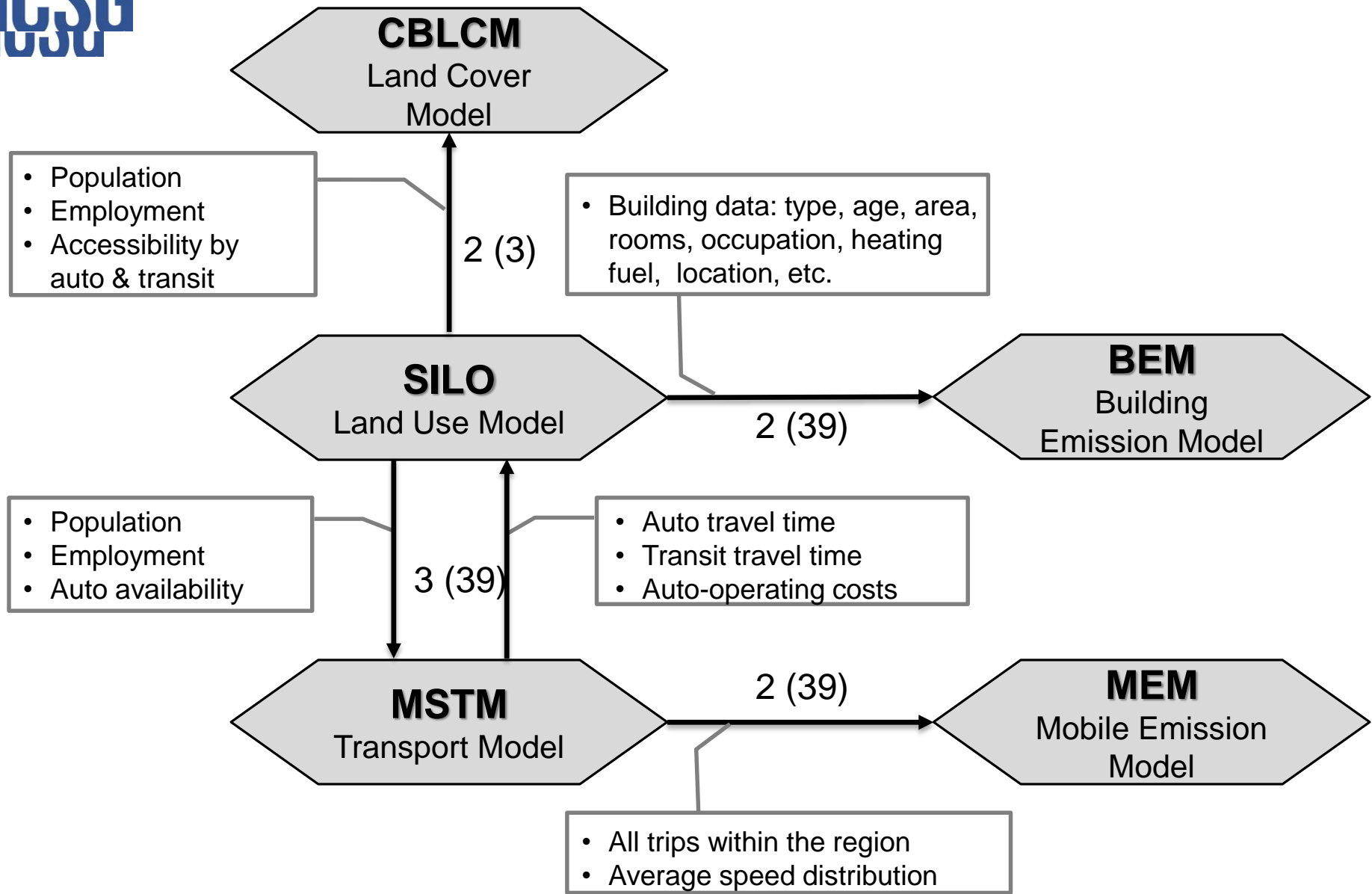
* Server: 20 x AMD Opteron Processor 6328 @ 3.20GHz, 42GB RAM, Windows 7

23 hour



Number of runs (simulated years)	
SILO	39
MSTM	3
MEM	2
BEM	2
CBLCM	2

Data flow between the models

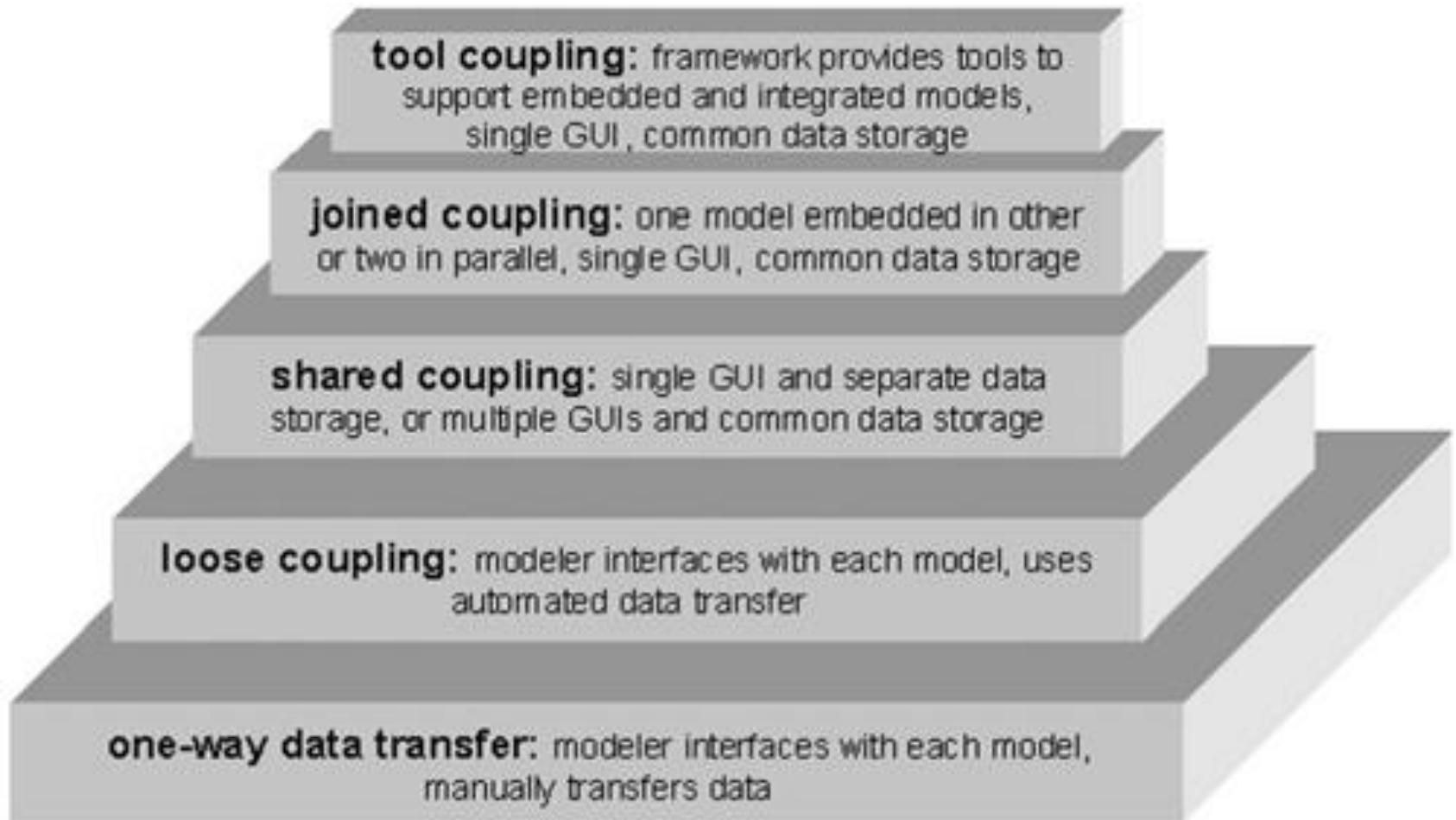


Key Requirements of Integration



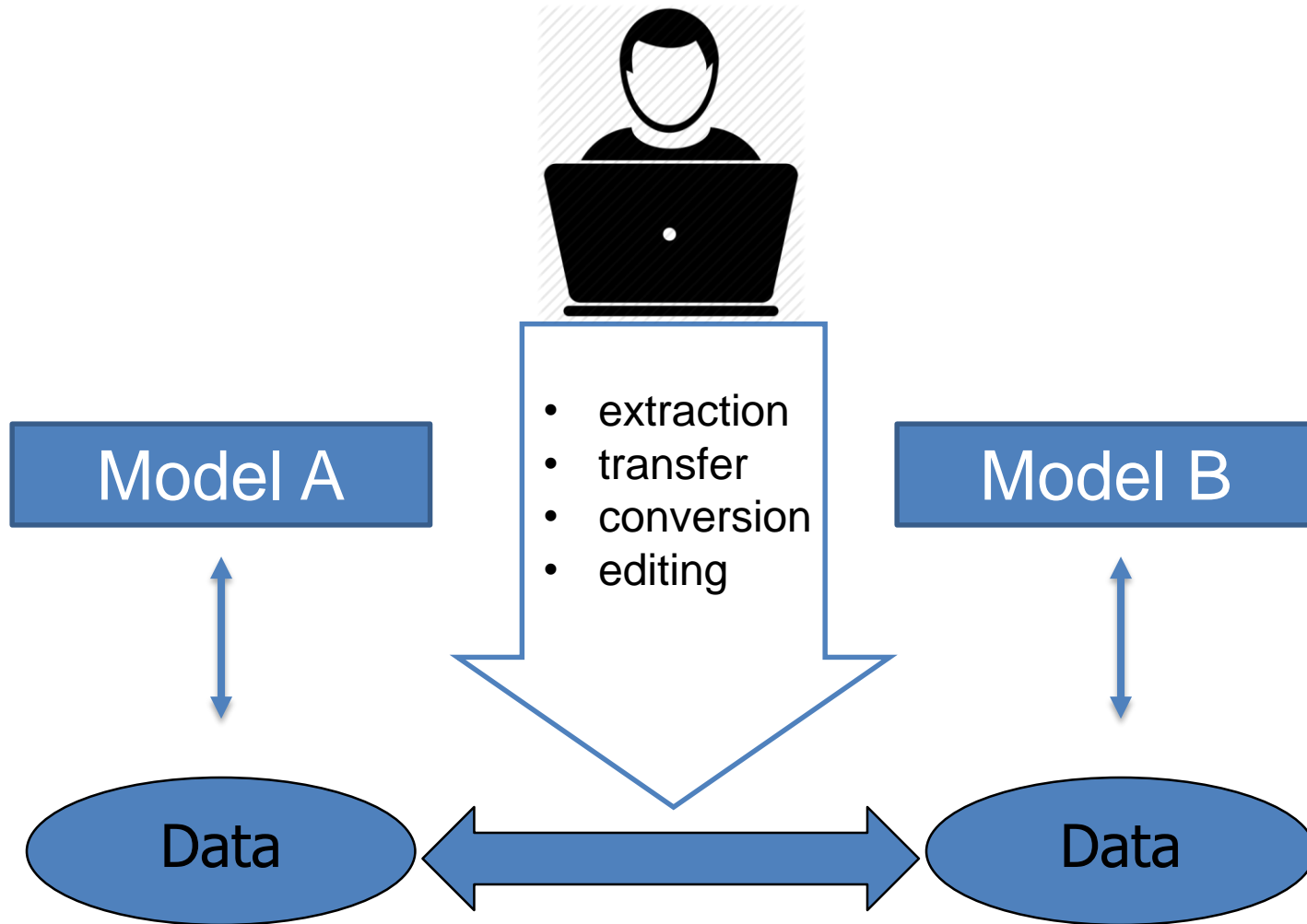
- Ability to develop models independently, such that they may be plugged-in easily.
- A modular approach supporting reusability and adding new components.
- User friendly graphical interface.
- Minimizing manual data transfer.
- Minimal or no change in source codes of the models.
- Capacity to link models developed in different programming languages and environments.
- Ability to deal with different licensing requirements.
- Compatibility with GIS for easy data visualization and spatial analysis.
- Minimal costs and efficient timing for implementation.

Progression of coupling methodologies

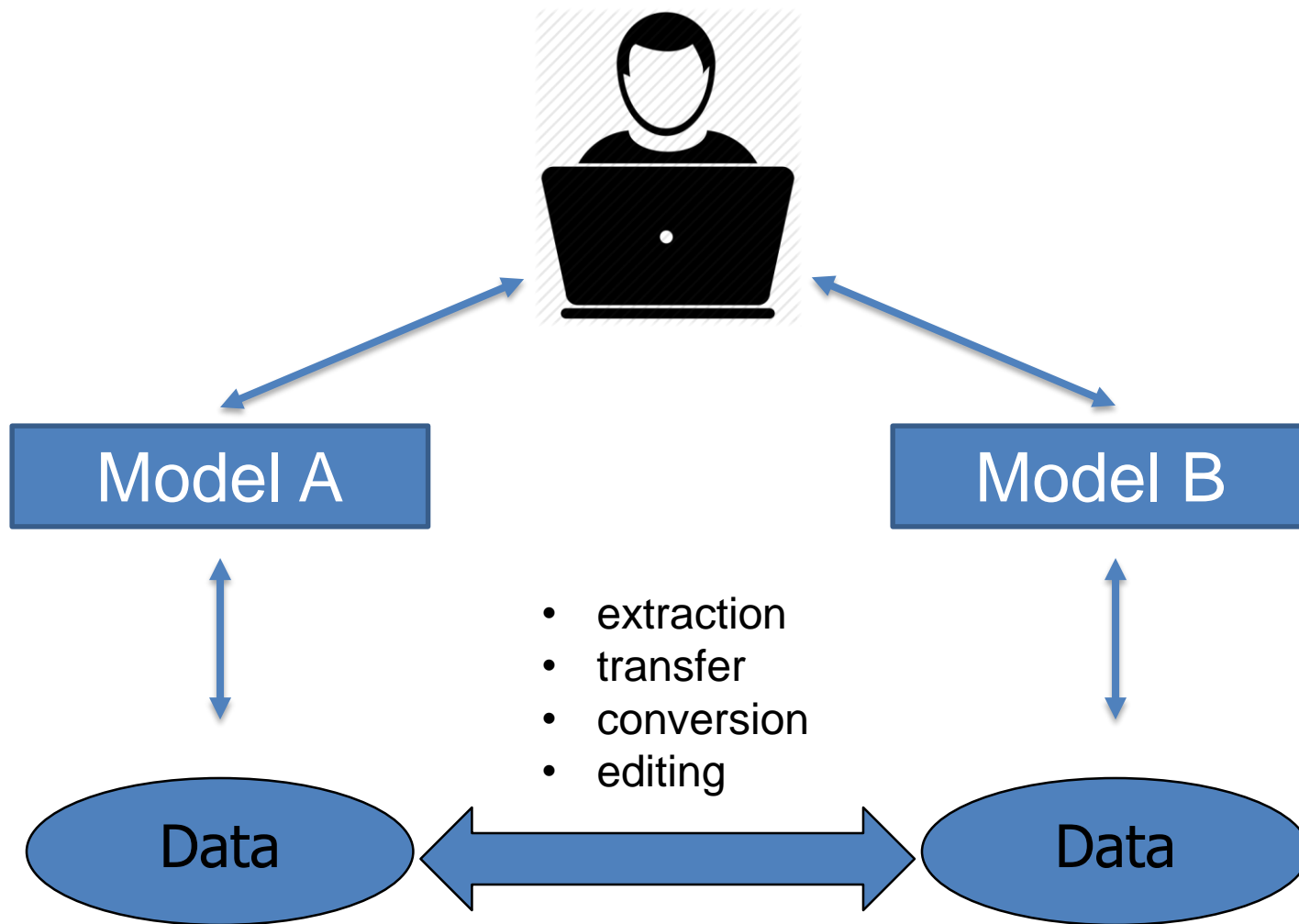


Source: Brandmeyer, J. E. & H. A. Karimi (2000). "Coupling methodologies for environmental models." *Environmental Modelling & Software* **15**(5): 479-488.

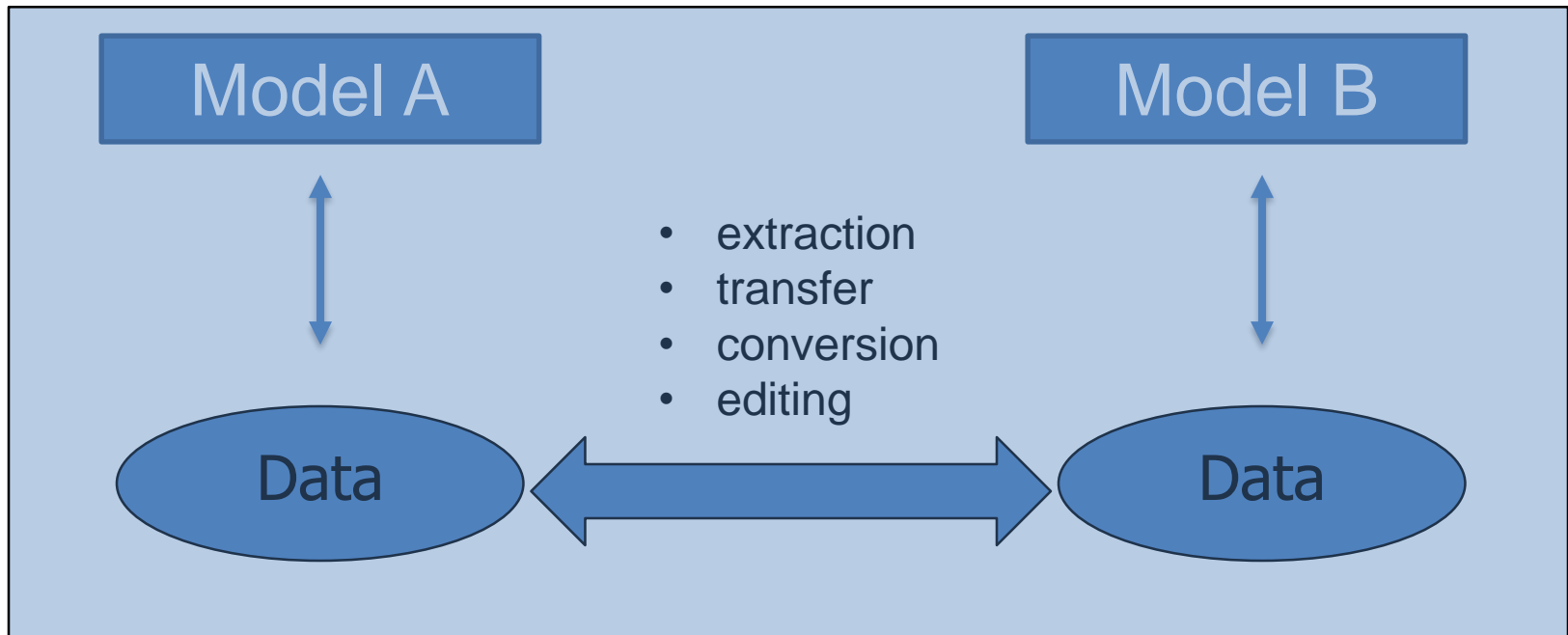
Manual Data Transfer



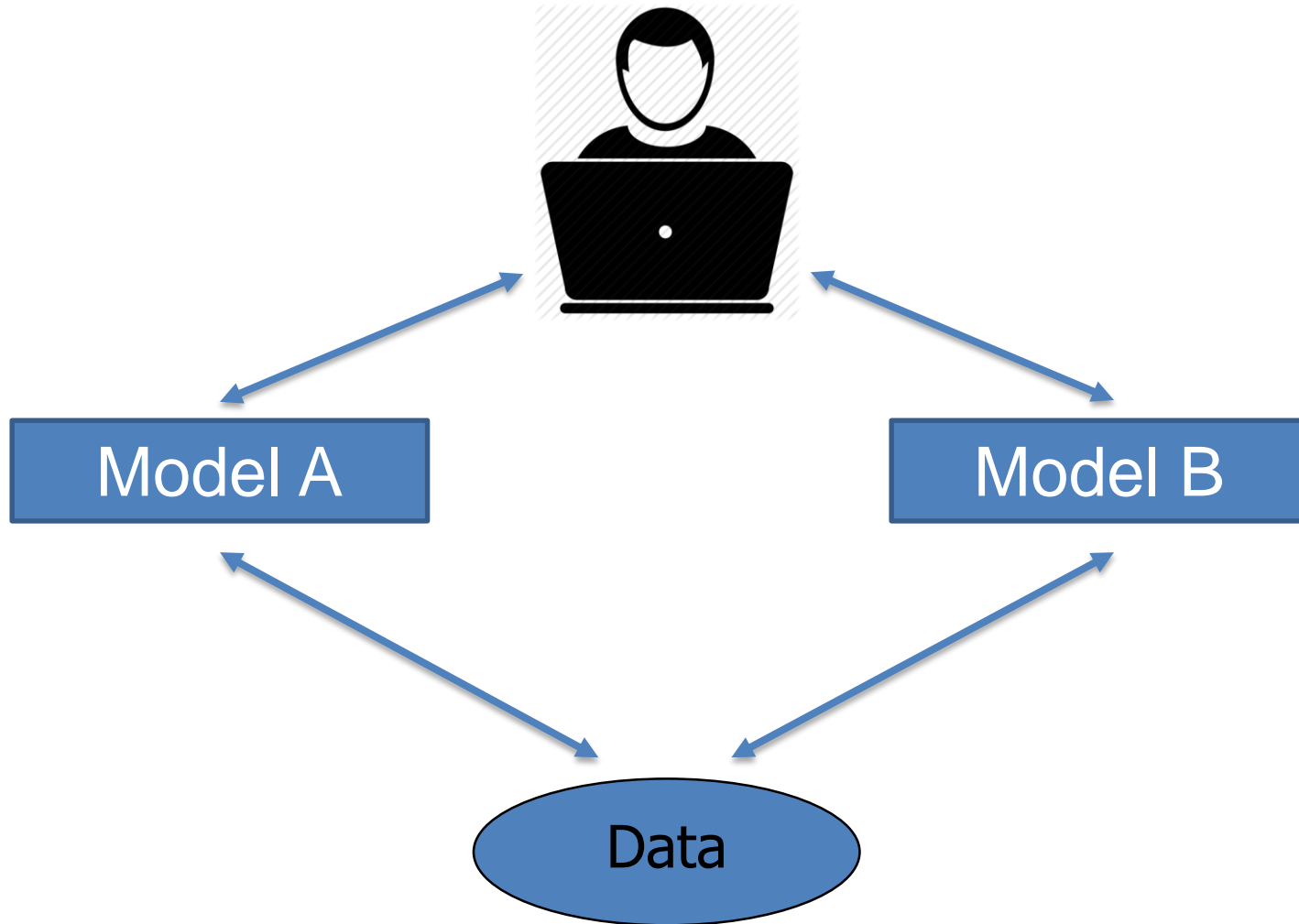
Loose Coupling



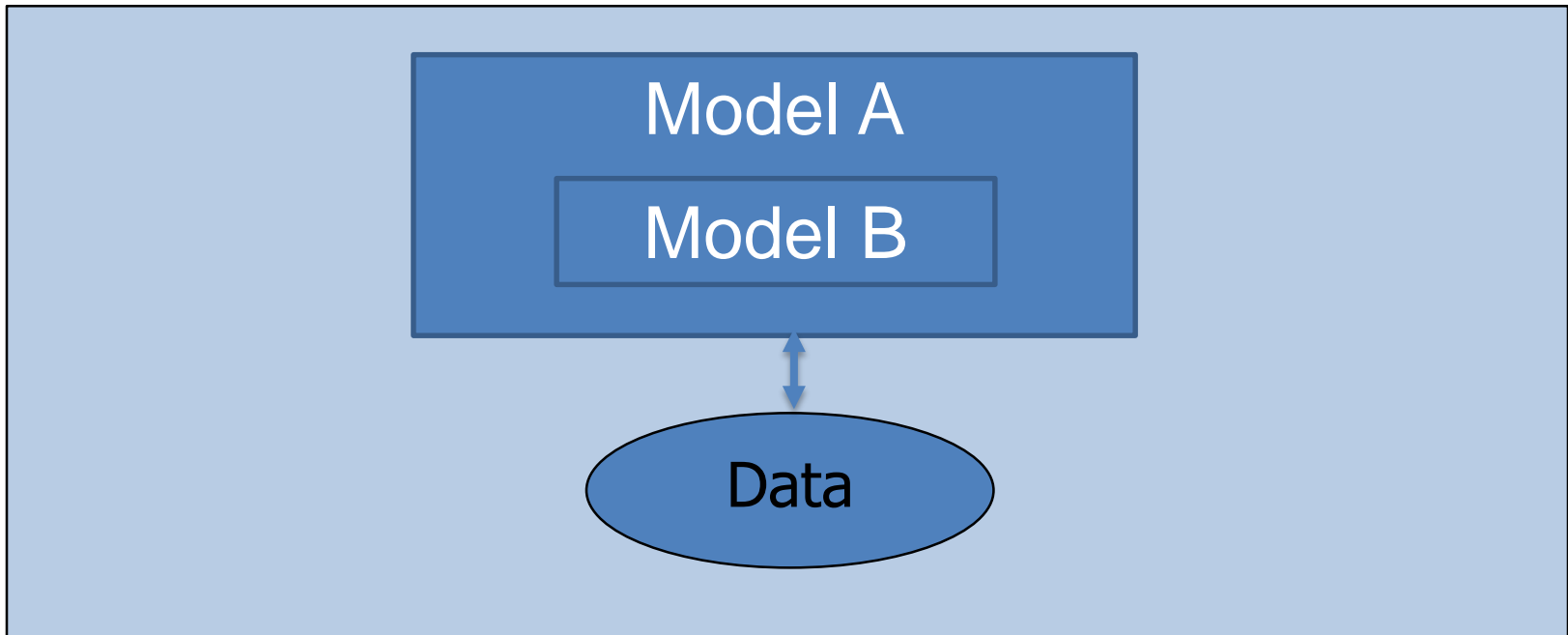
User Interface Coupling



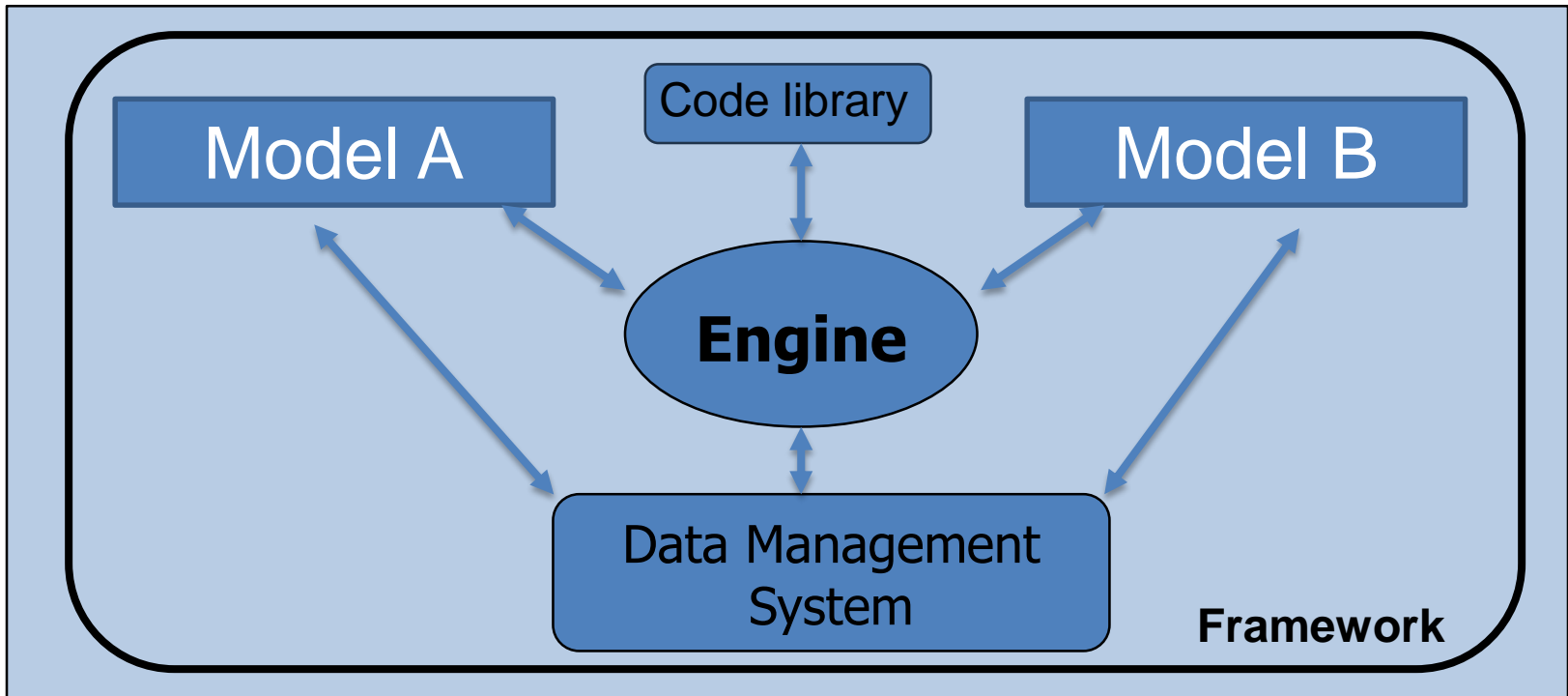
Data Coupling



Embedded Coupling



Tool Coupling



Model Coupling Tools



- Open Modelling Interface (OpenMI)
- Community Surface Dynamics Modeling System (CSDMS)
- Earth System Modeling Framework (ESMF)
- Model Coupling Toolkit (MCT)
- O-PALM
- OASIS
- FLUX
- Kepler



Open Modelling Interface



<http://www.openmi.org>

Compliant components can

- be configured to exchange data during computation (at run-time)
- run simultaneously and share information at each timestep.

Linked components may

- come from different suppliers,
- represent data and processes from different domains,
- be based on different concepts,
- have different spatial and temporal resolutions and representations.

Implementation requirements:

1. Save the model in DLL format.
2. Separate initialization, Perform time step & finalization parts in the source code.

```
void Initialize(IArgument[] properties)

string ComponentID
string ComponentDescription
string ModelID
string ModelDescription
ITimeSpan TimeHorizon

IInputExchangeItem GetInputExchangeItem(int index)
IOutputExchangeItem GetOutputExchangeItem(int index)
int InputExchangeItemCount
int OutputExchangeItemCount

void AddLink (ILink link)
void RemoveLink(string linkID)
string Validate()

void Prepare()
IValueSet GetValues(ITime time, string linkID)
ITimeStamp EarliestInputTime

void Finish()
void Dispose()
```




CSDMS

COMMUNITY SURFACE DYNAMICS MODELING SYSTEM

<http://csdms.colorado.edu/>

Deals with the Earth's surface - dynamic interface between lithosphere, hydrosphere, cryosphere, and atmosphere.

- Provides open-access to numerical models.
- Converts existing models into plug-and-play components.
- Can be applied for the models developed in C, C++, Fortran, Java & Python.
- Requires specific changes in the code.

The screenshot shows the CSDMS Web Modeling Tool interface. The header panel at the top contains the title 'The CSDMS Web Modeling Tool', the user email 'mark.piper@colorado.edu', and a 'Sign Out' button. The model panel on the left shows a dropdown menu for 'Model (*CEM 1)' with a 'CEM' dropdown and buttons for 'river' and 'waves'. The parameters panel on the right is titled 'Parameters (CEM)' and contains a table of configuration options:

Grid	
Number of rows in the computational grid	50
Number of columns in the computational grid	1,000
Grid resolution in cross and along-shore direction (m)	100.0
Coastal Geometry	
Gradient of the shoreface (-)	0.01
Water depth of the shoreface (m)	10.0
Gradient of the shelf (-)	0.001
Sediment flux flag	1

Table 1
Advantages and disadvantages of the five coupling methodologies

Methodology	Advantages	Disadvantages
One-way data transfer	Programming changes to the models unnecessary. Source code not required; suitable for proprietary models. Faster implementation with lower initial cost. Suitable for converting data between model versions.	Data conversion required between spatial and temporal scales, data file formats. Manual data editing. Quality assurance required for data conversions. New conversion procedures required when update model or system. User responsible for documenting all data transfer and conversion steps. Increased modeler, simulation time.
Loose coupling	Lower initial cost. ^a Can link models and components with minimal changes to existing code. Testing protocols address each model, not direct model interactions. Independent model development path. Supports distributed computing. Supports encapsulation for object-oriented programming (OOP). Potentially reduced training time due to intuitive GUI. ^b	Data conversion programs required between each set of coupled models. Conversion maintenance when data structure changes for one model. Data redundancy problems. Requires permanent data keys. Performance depends on network speed.
GUI coupling	Potentially easier to create input files. Potentially reduced execution time through reduced user interaction time. Supports proprietary code. ^c	Additional layer between model and user, without improving the model. Required automation of all model interactions. Model update requires GUI update. Programmers must anticipate all model applications and user needs.
Data coupling	Simpler data maintenance. Supports DBMS for consistency and easier maintenance. Reduced number of file conversion programs. Improved version control for data. Elimination of data redundancy. Supports data queries.	Potential limitations on data types. Rich language supporting geospatial and attribute data types, relationships. Overall model performance depends upon DBMS, server speed. Model interfaces depend upon DBMS.
Embedded coupling	Reduced development cost. Access to master model capabilities. Reusability for master model's code. Eliminates network communications.	Requires single computing system. Source code required for embedded model. Functionality limited to language provided by the master. Difficulty of code optimization. Changing the master may require changing embedded models. Increased computer requirements if all possible techniques and models are embedded. ^d
Integrated coupling	Promotes code reusability. Supports distributed, heterogeneous computing environments. Reduced model development cost.	Higher initial cost to facilitate integration of additional components. Network affects component performance. Shared routines required throughout the heterogeneous environment.
Tool coupling	Supports community model development. Supports both legacy and new models. Supports version control for data and code. Supports encapsulation for OOP. Supports distributed computing. Supports automated data backup. Supports DBMS with data dictionary.	Higher initial cost due to framework design and development. Relies on network and server speed. Model applications and user needs must be anticipated. Requirement for rich data language.

^a Charnock et al. (1996).

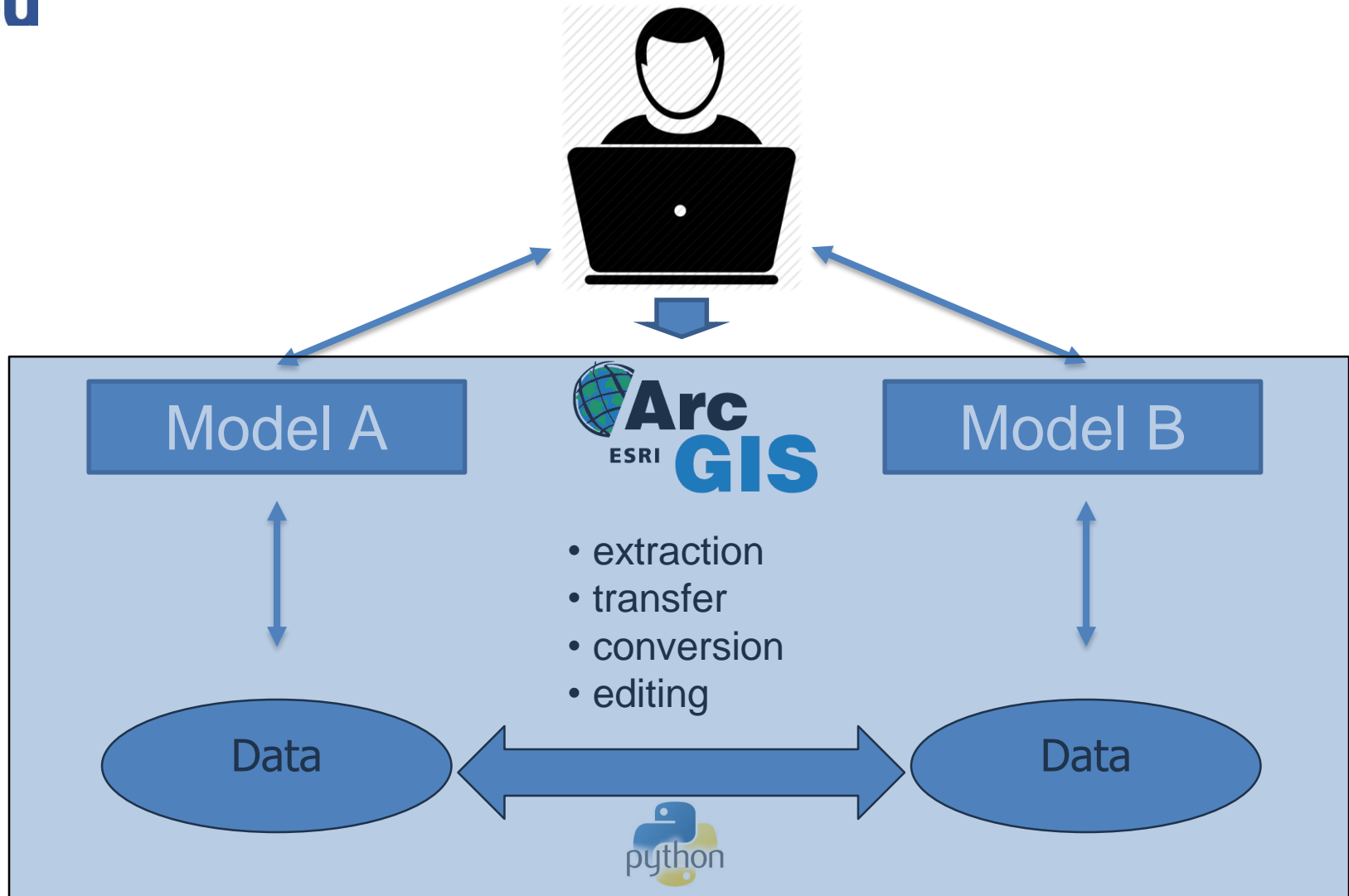
^b Mandel (1997).

^c Blodgett et al. (1995).

^d Arentze et al. (1996).

Source: Brandmeyer, J. E. & H. A. Karimi (2000). "Coupling methodologies for environmental models." *Environmental Modelling & Software* 15(5): 479-488.

Loose Coupling with Shared User Interface

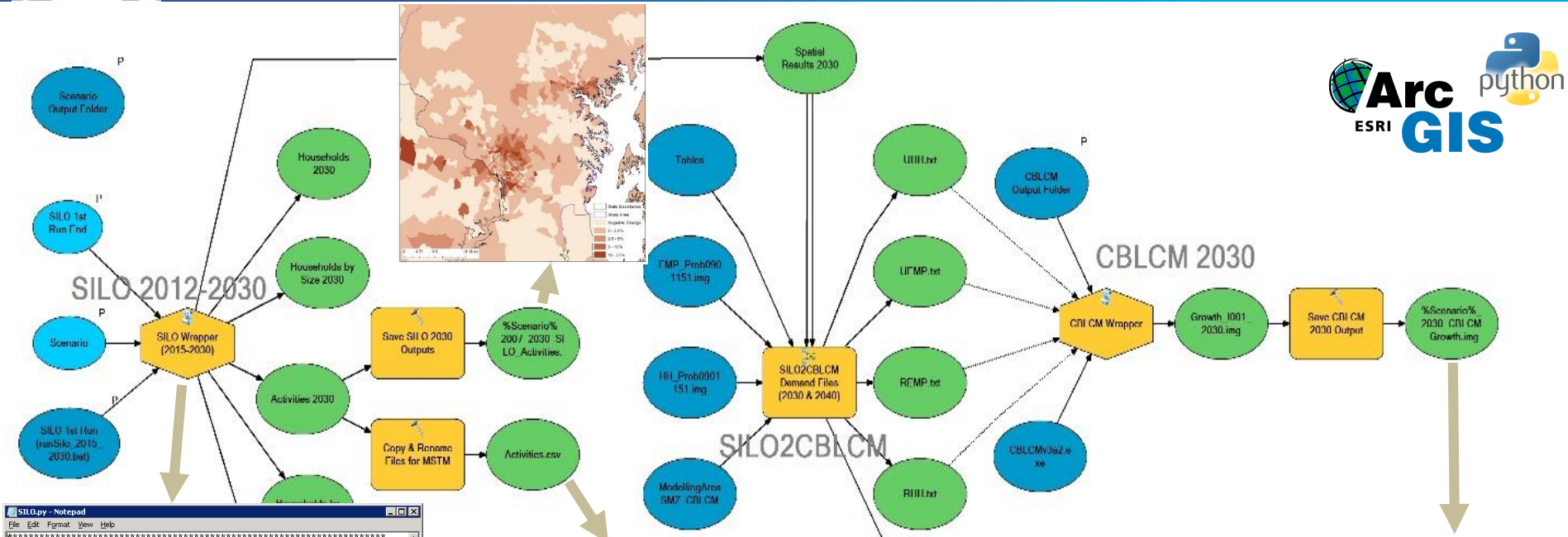


Python for Model Integration



- Specific libraries:
 - scientific programming (SciPy),
 - modeling and data analysis (Pandas),
 - visualizations and parallel computing (IPython)
- Language interoperability - often used to glue other programming languages:
 - MatLab (MLabWrap), R (RPy), Excel (OpenPyxl), FORTRAN (F2PY, PyFort), Delphi (Python4Delphi), Java (Jyton, JPyype, Jepp), Perl (PyPerl), PHP (PiP), C/C++ (Ctypes, Cython, SWIG)
- Runs natively on Windows, Mac and Linux.

Python Wrappers & ArcGIS Model Builder



```

SILO.py - Notepad
File Edit Format View Help
Description:
Run SILO (model)
Arguments:
0 - Model exchange folder
1 - Data exchange folder
2 - Shared file
3 - Exported shared file
Created by: Harutyun Shahumyan
Standard error handling
try:
import arcpy
import shutil
import time
import os
import string
import sys

start = time.time()
arcpy.AddMessage("")
arcpy.AddMessage("SILO model start time: %s" % time.strftime("%x %x %2")

# Get input arguments
In_Program = arcpy.GetParameterAsText(0)
In_SILOPropertyFile = arcpy.GetParameterAsText(1)
In_ExchangeFolder = arcpy.GetParameterAsText(2)

# Check that the program exist
if not arcpy.Exists(In_Program):
    raise Exception, "Input program does not exist"

# Run the model / program
arcpy.AddMessage("")
arcpy.AddMessage("running %s" % (In_Program))

import subprocess
#subprocess.call([In_Program])
#subprocess.call(["java", "-mx4000m", "-classpath c:/models/silo/mstm

#propfile=string.replace(In_SILOPropertyFile, "\\", "/")
#propfile=string.replace(In_Program, "\\", "/")
#arcpy.AddMessage(propfile)
#runjava = "java -mx4000m -classpath "+In_Program+";c:/models/silo/mstm
#os.system(runjava)
#arcpy.AddMessage(runjava)

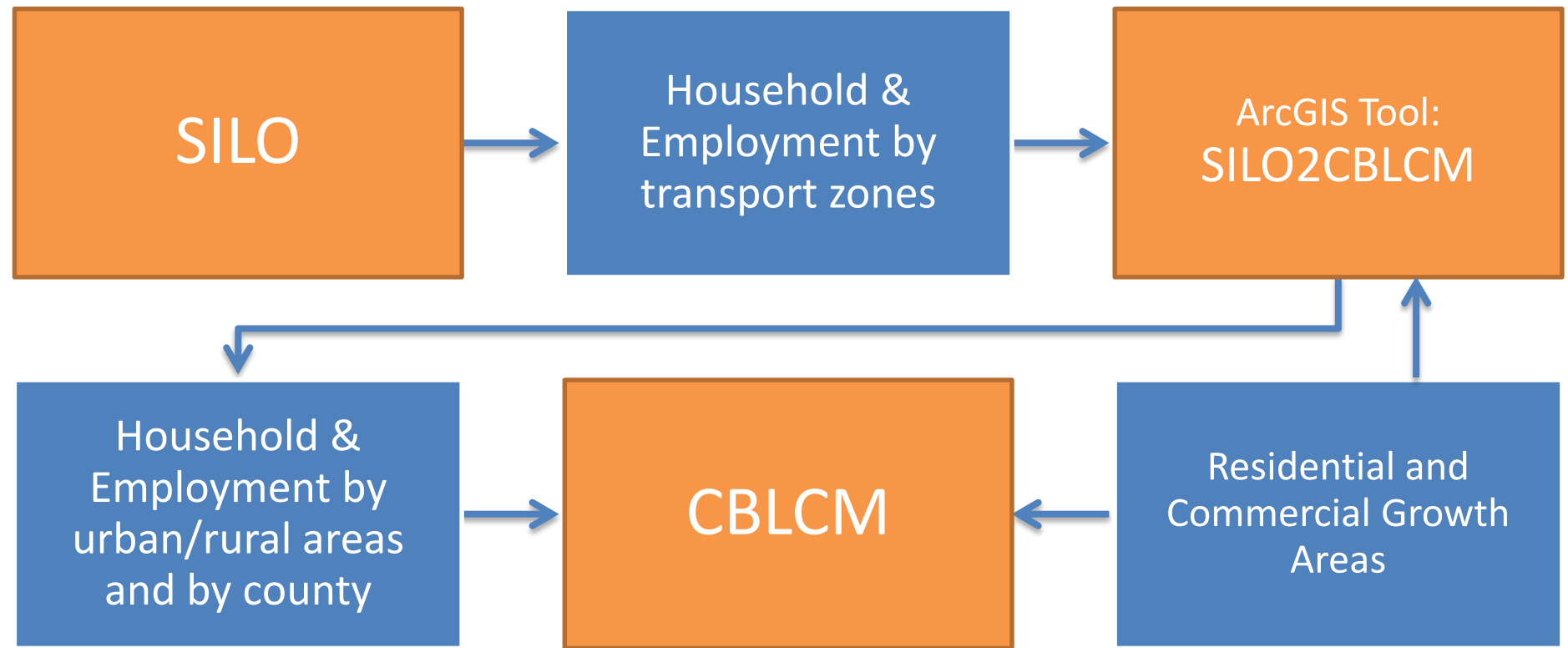
siloClassPath="c:/models/silo/mstm;c:/models/silo/mstm/javaFiles/siloms
os.system("java -mx4000m -classpath "+siloClassPath+" com.pb.siloms
    
```

Activities.csv - Excel

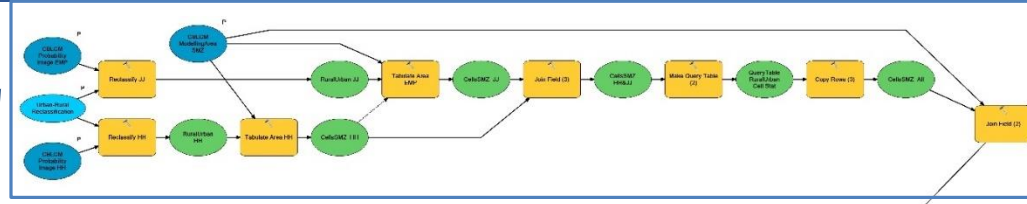
	A	B	C	D	E	F	G	H
1	SMZ_N	ACRES	HH2007	ENR	RE2007	OFF2007	OTH2007	TOT2007
2	1	1603.51	10222	1706	373	999	829	2326
3	2	907.2264	1885	1062	525	998	1005	2626
4	3	758.8692	1049	1447	92	1200	740	2957
5	4	170.1724	637	0	96	628	390	1173
6	5	820.4843	4356	304	584	2532	3188	6533
7	6	1596.518	3552	3272	456	1239	1154	2998
8	7	421.9648	1651	913	420	431	251	1154
9	8	472.3039	3814	1247	103	173	145	447
10	9	553.1476	2819	882	74	1015	1275	2425
11	10	490.9006	3561	724	457	292	211	1009
12	11	715.3842	5897	1418	184	831	843	1969
13	12	763.0019	2502	5198	177	715	710	1703
14	13	447.3607	3013	1373	26	698	1052	1817



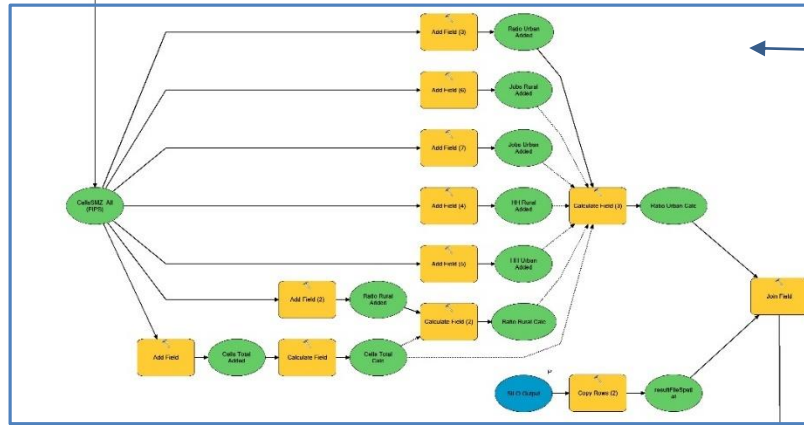
Organizing Data Flow



Adapting SILO Output for CBLCM

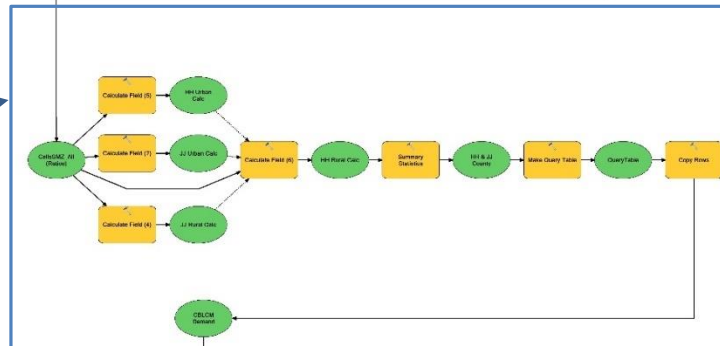


Counts commercial (JJ) and residential (HH) cells in rural and urban areas based on CBLCM growth images.

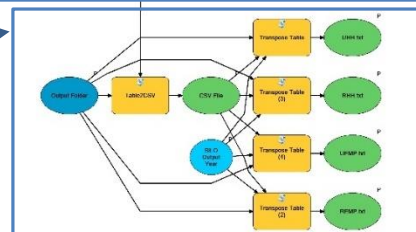


Calculates the ratio of the rural and urban residential and commercial cells and joins the table with SILO households and jobs table

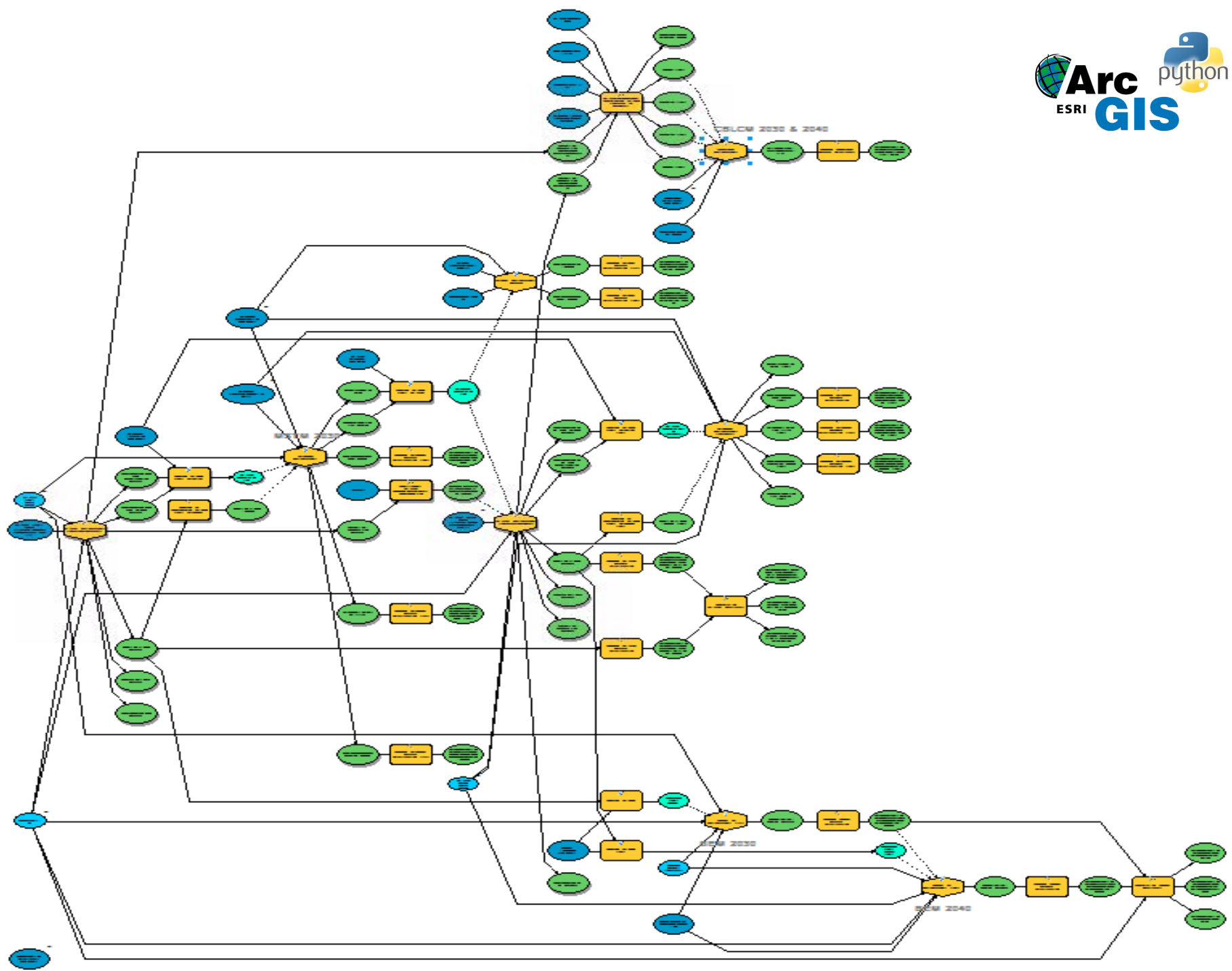
Calculates the CBLCM demand table as the rural and urban job and household numbers.



Exports the CBLCM demand table as a csv file and saves it in 4 separate text files as required by CBLCM



SILO2CBLCM



Python Wrappers



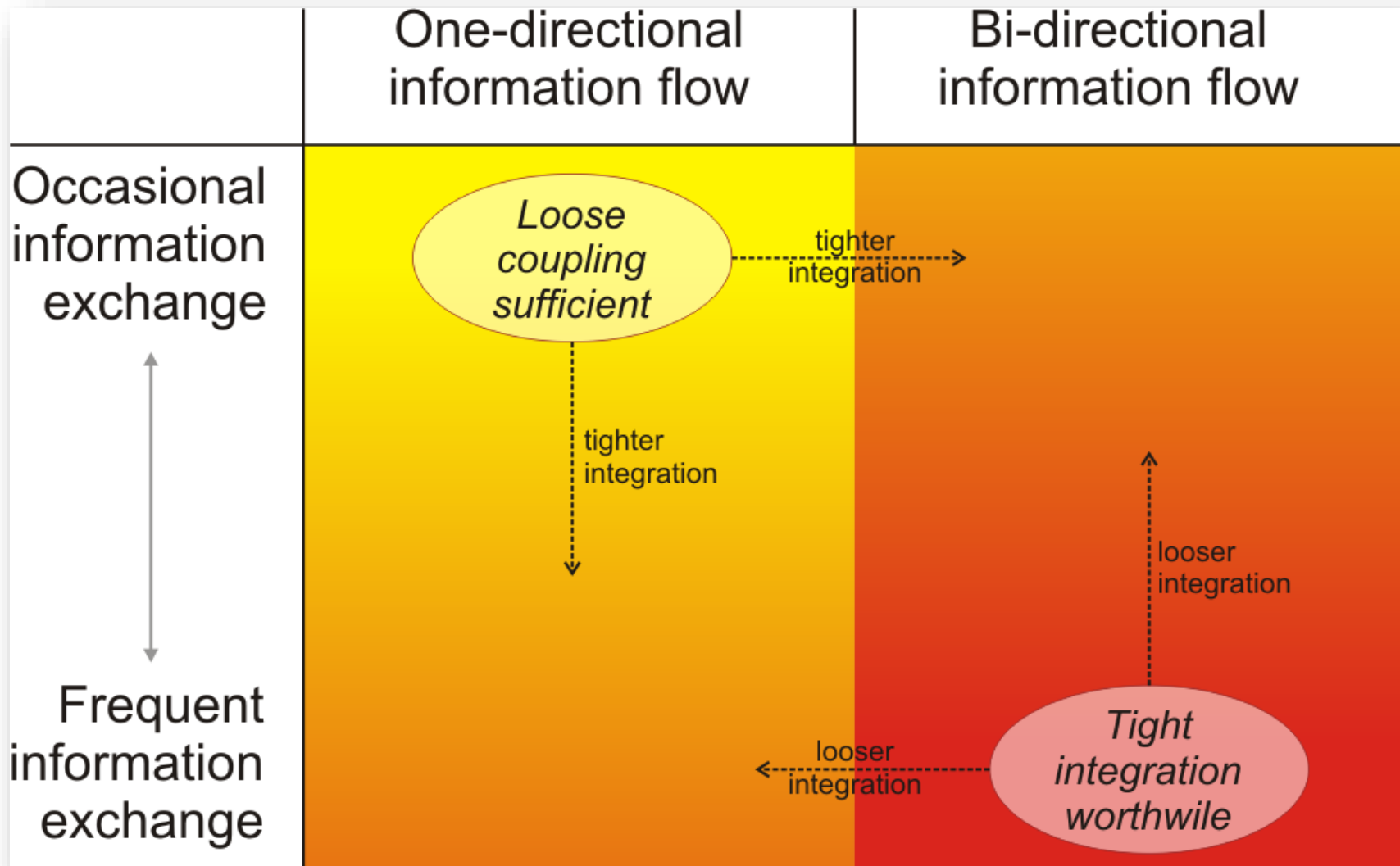
Benefits

- No need to change the source codes of the models.
- Runs models developed in different environments.
- Can be extended with additional models over time.
- General user interface showing process flow.
- Rich visualisation & mapping capabilities with ArcGIS.
- Easy to implement.

Limitations

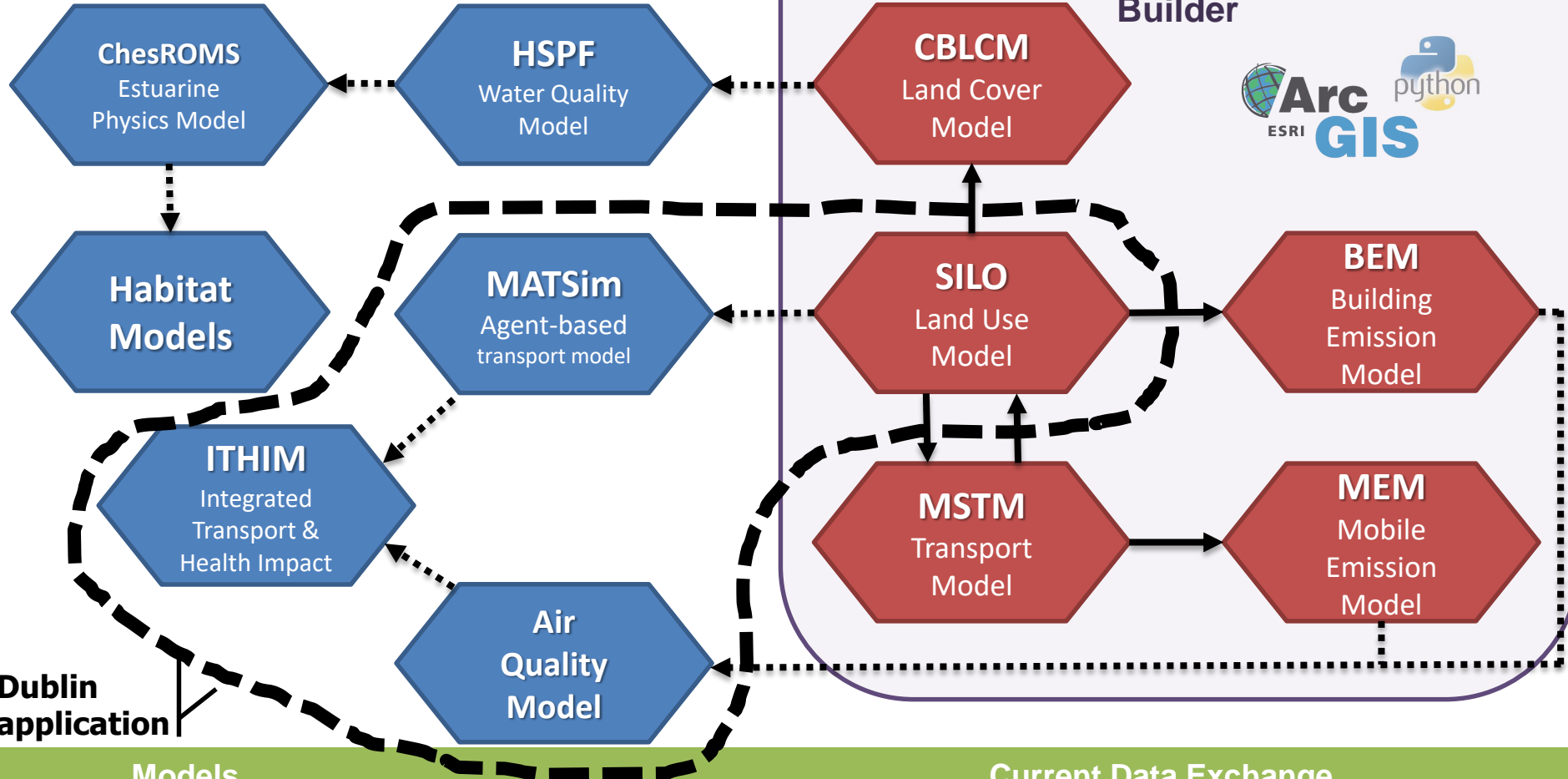
- Parallel model runs and dynamic data exchange during simulation time steps are not supported.
- Model processes run independently from one another.
- Data exchanged between modules are written to and read from a hard drive. No in-memory data exchange.

Reasons for loose coupling and tight integration



Courtesy of Dr Rolf Moeckel

Status & Potential Enhancement



Models		Current Data Exchange	
	Installed and coupled on the SESYNC server		Automatic data transfer (loose coupling)
	Installed on different remote servers or PCs		Potential links

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Integration of land use, land cover, transportation, and environmental impact models: Expanding scenario analysis with multiple modules



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Abstract

It is an expensive and time-consuming task to develop a new model. Furthermore, a single model often cannot provide answers required for complex decision making based

This Article

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Dublin Case Study

Box 3 Dublin metropolitan area: rapidly growing economy and population

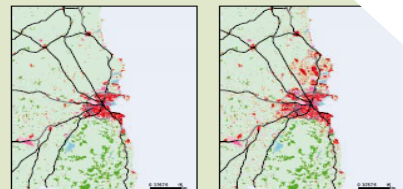
Dublin is a relatively small city by European and international standards. However, it dominates the urban pattern of Ireland in terms of demography, employment and enterprise (Bannon, 2000). The Greater Dublin metropolitan area population was 1 535 000 in 2002, 40 % of the total Irish population. The National Spatial Strategy (2002) suggests that by 2020 the Greater Dublin area population will be in the range of 1.9–2.2 million. The strong growth of the Greater Dublin area is the result of the region's role both within Ireland and as a European capital city. Consequently, the Dublin area will need to accommodate 403 000–480 000 additional inhabitants by the year 2020.

Population growth and economic development, as well as housing pressure, are expected to be the main drivers of land use change in the Greater Dublin area during the next 15 years. Housing prices in Dublin are a significant push factor driving the population towards the suburbs, where it is cheaper to buy or build a house. Another push factor is the need for more space to accommodate growing families with children needing more space to move and play. The Dublin region is also facing a housing crisis and housing more affordable. Personal housing preferences are also a factor, with a preference for the Irish housing ideal (Michell, 2004). This preference is being met by the benefits of the proximity to the capital city and the facilities provided by the planning regime which imposes a low-density housing areas.

Urban-rural migration in the Greater Dublin area is also a factor. The growth of transport, suggesting a preference for employment. Another push factor is the need for orbital roads and rail networks to facilitate the journey through the centre. Other factors include the Dublin-Belfast corridor. This development is a more sustainable form of development over the period.

The regional MOLAND model, covering the following 9 counties: Dublin Co., Wick Co., Carlow Co., Kildare Co., Wexford Co., Wick Co., Galway Co., Kerry Co., and Cork Co., estimated to increase by 110 % over the next 20 years. The 2025 scenario also suggests the Dublin-Belfast corridor. This development is a more sustainable form of development over the period.

Map Dublin 1990 and modelled scenario for 2025



Source: MOLAND (IRC).

European Environment Agency (EEA) cite Dublin's sprawl as 'worst-case scenario', states such as Poland might avoid making the same mistakes...

sprawl The long commute

Dublin's commuter belt now extends over 100 kilometres from the Dublin area, Dr Brendan Williams talks to Louise Holden about the implications of this development.

When Dr Brendan Williams and his team published the findings of their third study on housing in Ireland last month, the media response was predictable. The report reached conclusions about the trajectory of Dublin property values: the national duties ran with yet more headlines about house prices. However, this report had a great deal more to say about the impact of housing patterns than media reports might suggest. Where we build, and where we choose to live, has implications that ripple out through our health, schooling, healthcare, leisure, social life, the local environment, economy and the global

are filling up. It's an unsustainable pattern, according to Williams, and one which requires a bird's eye view to address. "People tend to identify with issues that relate to their local area," says Dr Williams. "It's fine for people to be interested in the local market or the services available to them, but we need an overview. There are lots of individuals, groups and authorities debating the issues but no one is looking at the whole picture."

Well-served and established townlands are emptying out while under-served, new regions are filling up.

According to Williams, there is a proposal for a greater Dublin Area Authority on the table as well as proposals for regional planning which are part of the National Spatial Strategy, but these have never been fully activated, and may

be in line with best international practice and reduce the risk of corruption," the report recommends. However, Dr Williams and his team are not on a mission to tear down the system. "We're not suggesting confronting the existing authorities. Many media reports claimed that we were forwarding the notion of planning watchdogs. That is not the case – even the term is conformational. Agreement between stakeholders, and meaningful resources, are required."

This is a non-debate within a much larger issue, and Williams is hopeful that his study will contribute to a more circumspect approach to planning and the environment. This report will contribute to a larger study, the Urban Environment Project coordinated by UCD, commissioned by the Environmental Protection Agency, to look at the long term impact of urban sprawl. This is an inter-institutional project that will examine urban development tomorrow climate change.



Map shows traditional Dublin commuter belt of 25km and newer commuter zone of 100km. © Ordnance Survey Ireland/Government of Ireland

Urban Sprawl and Market Fragmentation - Some key findings

1. Current levels of housing demand seem likely to maintain their momentum through to 2009.
2. Demand has been absorbed by the growth of the commuter belt which now stretches over 100 kilometres from Dublin through Limerick and into south Ulster. The pattern is contrary to the objectives of the National Spatial Strategy and Regional Planning Guidelines.
3. Adjacent towns and villages are swallowed by suburban development, potentially with negative consequences in terms of

HEADLINE: Dublin is cited as worst-case scenario of sprawl

BYLINE: Frank McDonald, Environment Editor, in Copenhagen

BODY:

Dublin's sprawl is being used by the European Environment Agency (EEA) as a 'worst-case scenario' of urban planning so that newer EU member states such as Poland might avoid making the same mistakes.

The EEA's major report to be published next month, the Copenhagen-based agency says Dublin, Madrid and Istanbul are case studies to show what can happen when urban sprawl is allowed to run out of control, according to its main author.

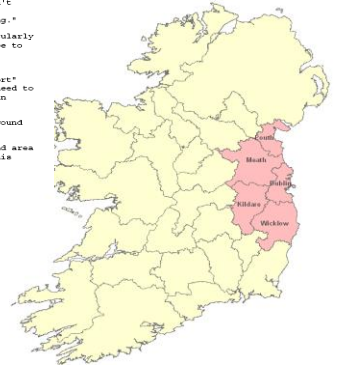
The EEA's spatial analysis unit, said Ireland was "very good" in relation to urban sprawl, not just in Dublin, but also in other cities throughout the country as a result of "extremely high density".

"Our results, were absolutely surprising. We couldn't have said that Dublin was a worst-case scenario because they showed that sprawl was so bad in Dublin that it was not the geography is not designed for such a thing."

"In all over Europe, Dublin's case was particularly relevant as a case for cities in eastern Europe to avoid making the same mistakes. It's about money flow without having a vision of the future."

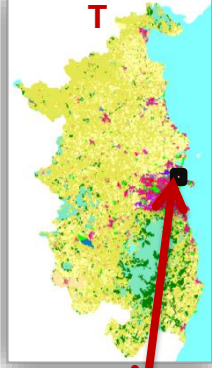
"The EEA states receiving 'massive support' from other cities, Mr Uebel said they "need to learn from Dublin why such development can be avoided."

Urban sprawl, not just around Dublin, but also in other cities, is addressing this issue.



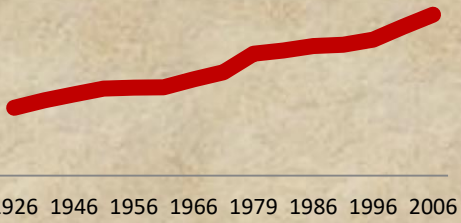
Three-quarters of all Europeans now live in urban areas and this is expected to rise to 90 per cent by 2020 based on current trends (EEA)

Land use map at time T



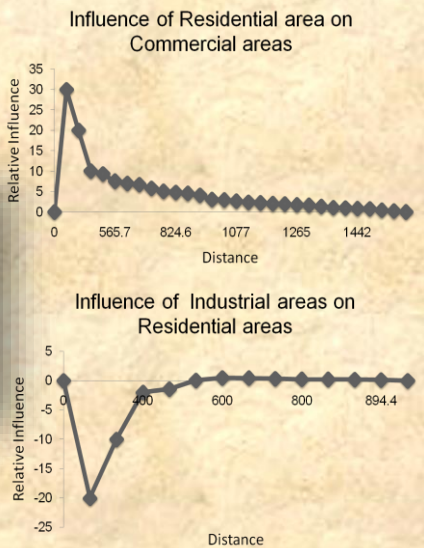
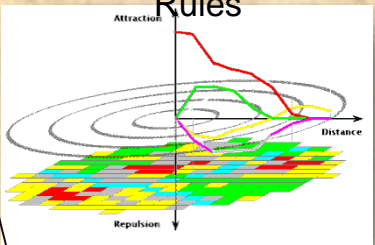
MACRO MODEL

Global Level
(Greater Dublin Region)
Population and Employment Trends

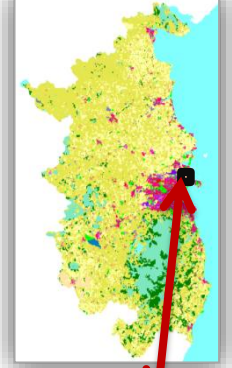


MICRO MODEL Local Level (426,500 cells)

Neighbourhood Rules



Land use map at time T+1

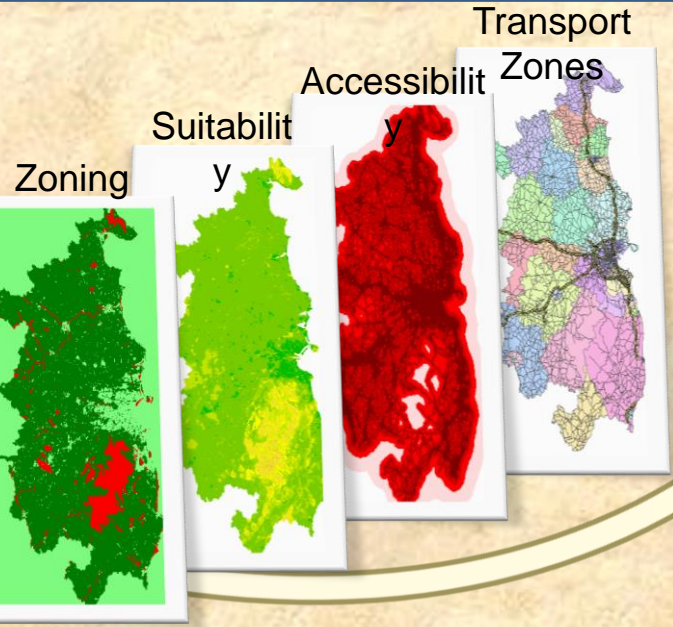


Time step: 1 year

Regional Level
(5 counties in the Region)

Socio-Economic Information

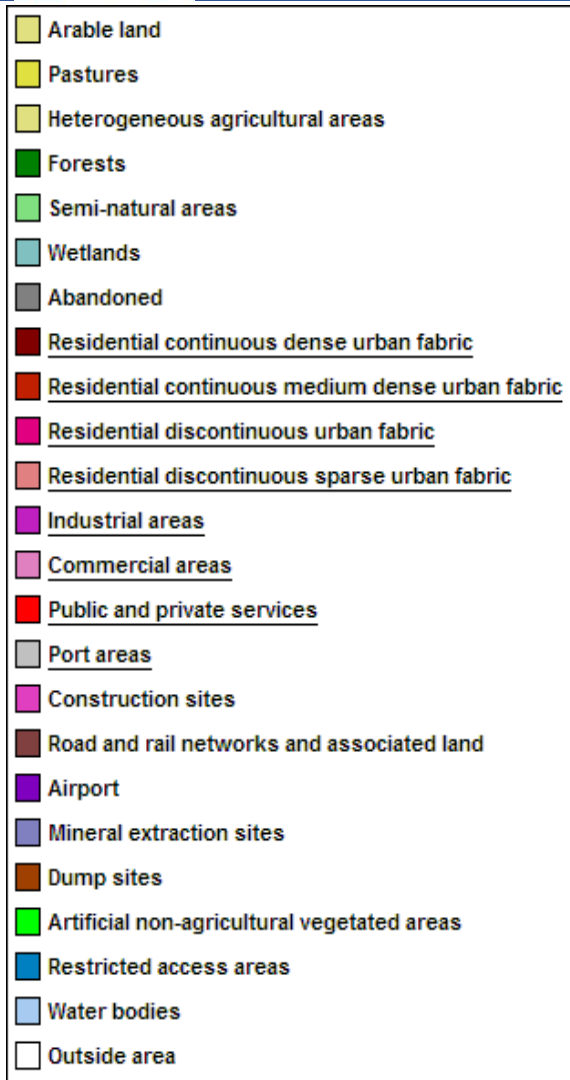
Region	Cell demand...	Productivity...	Crowding	Available sp...
Louth	143.902	157.941	1	20235
Meath	126.839	300.156	1	57366
Dublin	891.322	176.332	1	19877
Kildare	221.272	186.065	1	40831
Wicklow	107.584	230.658	1	49177



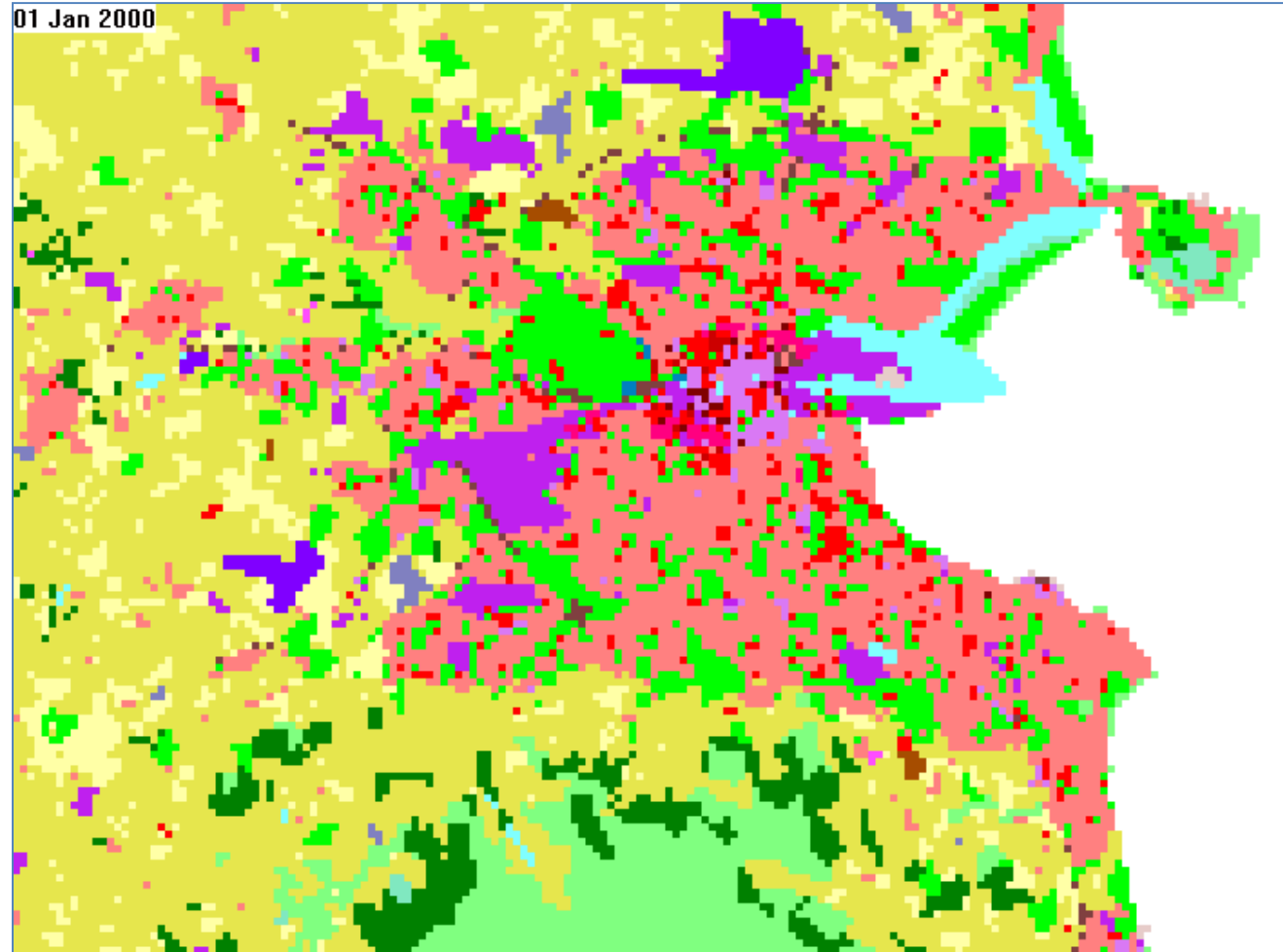
Time loop

Land Use Transition in the MOLAND Model

Sample MOLAND Simulation



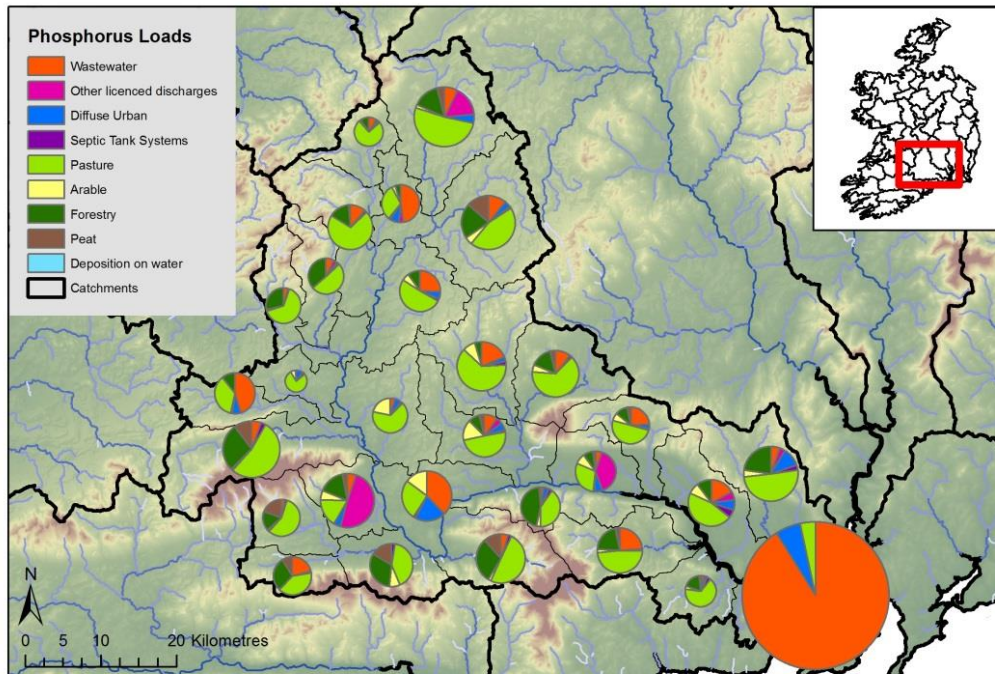
01 Jan 2000



SLAM: Source Loading Apportionment Model

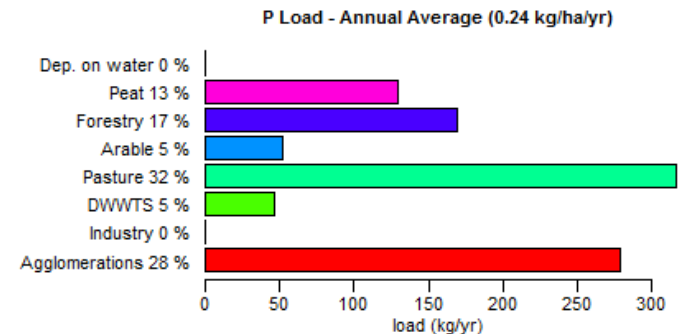
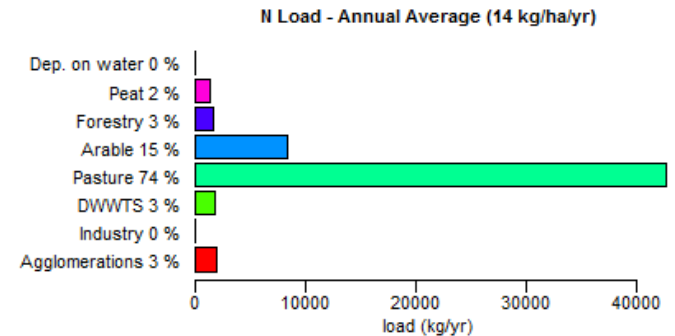
A source-oriented model that calculates the nitrogen & phosphorus losses to surface water from each sector in a catchment using monitoring data where available and GIS datasets.

- Purpose: To rank the sources (e.g. Agriculture, UWWTP) contributing to nutrient loads in a catchment.
- Output: Maps & charts showing proportion of nutrients attributed to each sector.



SLAM output example for Suir

BREAGAGH (TIPPERARY)_010 Load Apportionment Results - Draft v1.6



SLAM output for Ara sub-catchment

SLAM Sub-Models

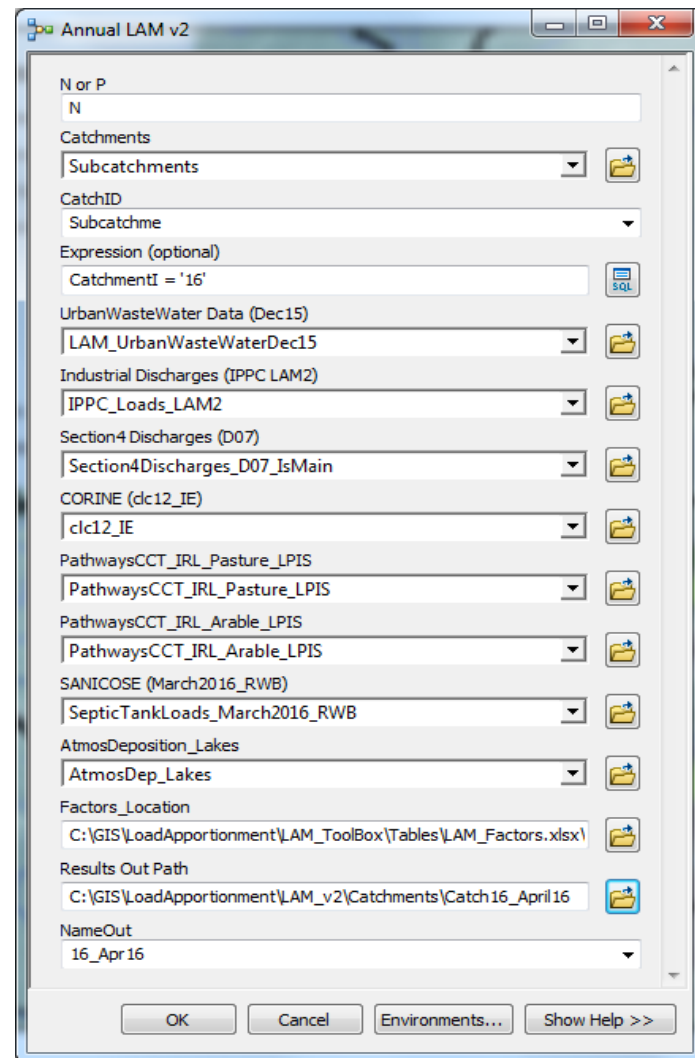
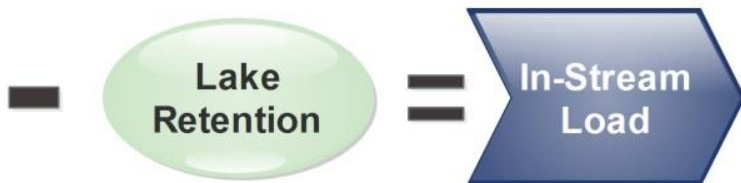
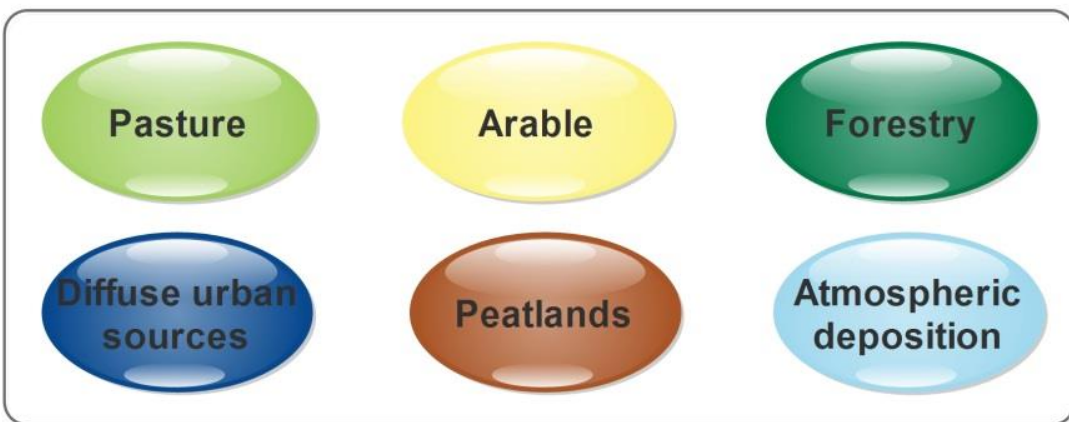


Direct Discharges



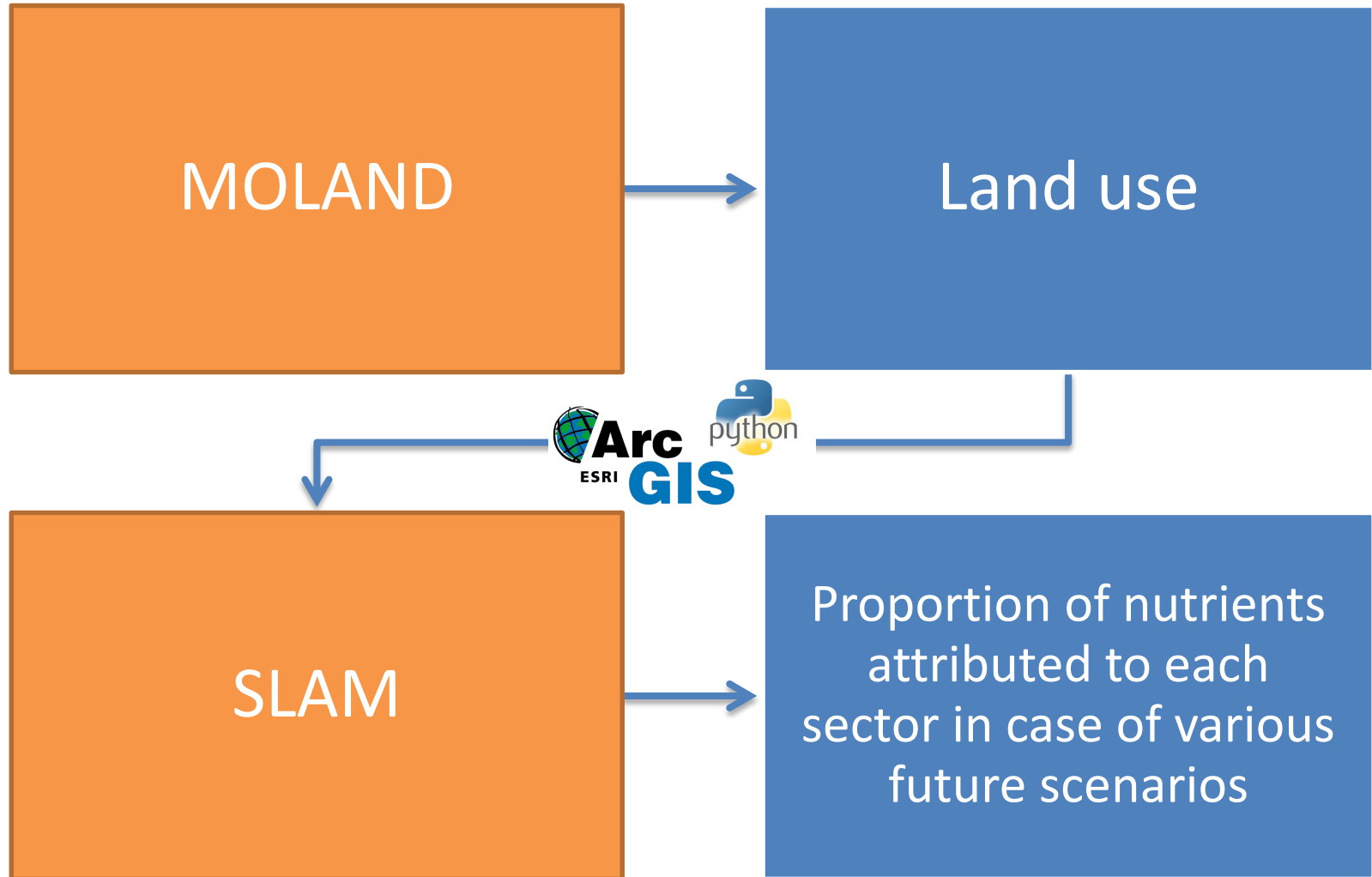
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Diffuse Nutrient Sources



Input screen for SLAM ArcGIS toolbox.

Coupling MOLAND and SLAM





Thanks

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