3RD
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Watershed modeling and nutrient loadings in Han River of RO Korea

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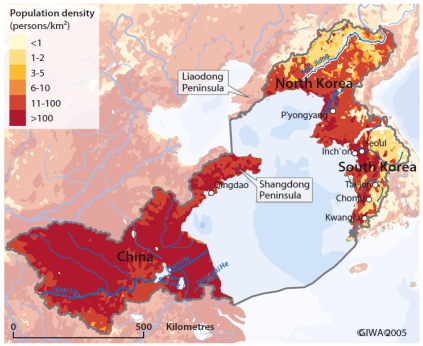
Background and Objective

- **Protection and management of the Yellow Sea**
  - Major cities and agricultural lands within the YS watershed
  - Total population: 600 million

    approx. 10% of the world's population (UNDP/GEP, 2007)
  - **Need to examine land-based pollution loads that effects the Yellow Sea ecosystem**
- **Study Objective**



Population density in the Yellow Sea region (Teng et al., 2005)

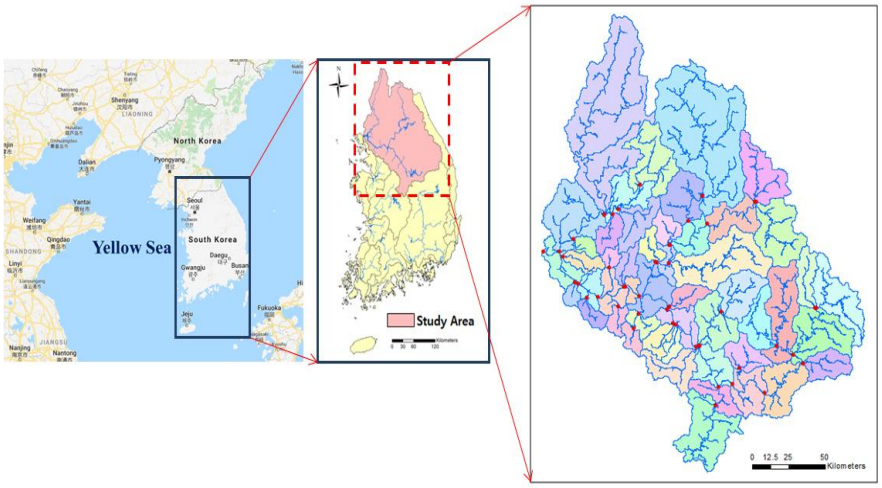
To estimate the spatio-temporal distributions of pollution loads from the Han River Watershed to the Yellow Sea

- **Examination of study area and pollution sources**
- **Model set-up of the Han River Watershed**
- **Analysis of land-based pollution loads**

Study Area

- In RO Korea, Han River has the greatest influence amongst the major rivers flowing into the Yellow Sea
- Han River Watershed
  - Total Area: 34,401.9 km^2
  - 34.3% of RO Korean Territory
  - Lies between two countries:
    - RO Korea: 27,919.8 (81.2%)
    - DPR Korea 6,482.1 km^2 (18.8%)

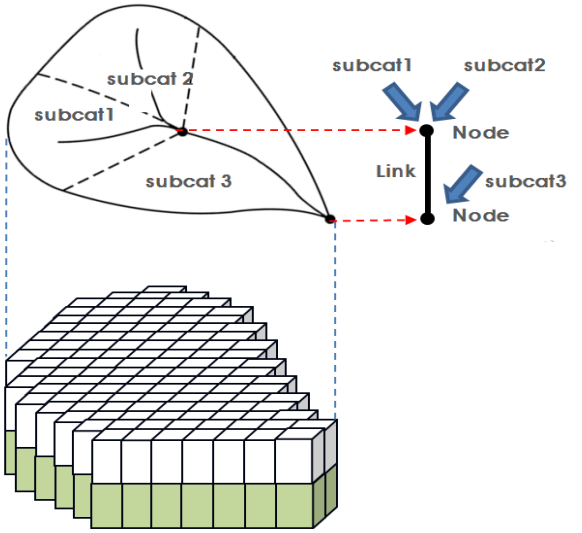
Major rivers flowing into the Yellow Sea	Area (km^2)
Han	**34,402**
Geum	9,912
Mankyoung-Dongjin	2,726
Youngsan	3,467



The location of the study area: The Han River Watershed

Watershed Model Selection

- **REDPOLL**(**R**egional **E**stimation of **D**iffuse **POL**lution **L**oads)
  - Development and implementation
    - A study on the Diffuse Pollution Loads Estimation at Diffuse Pollution Management Areas and Total Maximum Daily Load Management Area (MOE, 2016)
    - Purpose: to evaluate the spatio-temporal pollution delivery loads of large watersheds
  - Watershed discretization
    - Discretizes a watershed into **square grid cells**
    - Grid component: **1 soil layer, 1 aquifer layer**
    - Sub-watershed connection: **node-link networks**

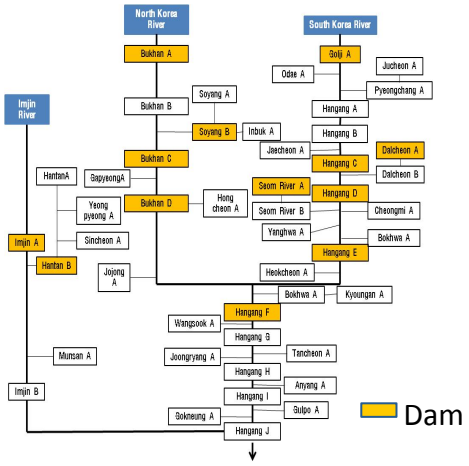


REDPOLL represents a watershed using a network of square grid cells

Watershed Discretization and Node-link Network Set-up

- **Han River Watershed discretization**
  - **49 sub-watersheds** based on TMDLMP (Total Maximum Daily Load Management Programs) watersheds
- **Node-link network set-up**
  - **Node-link networks** between the 49 sub-watersheds set-up
  - **Irrigation facilities (large dams and weir)** need to be considered

The 49 sub-watersheds of the Han River Watershed



A schematic diagram of node-link networks between the 49 sub-watersheds

Simulation Conditions and Input Data

❖ Simulation conditions

- Simulation time
  - Grid cells and sub-watershed process: **1 day**
  - River process: **1 hour**
    (Estimated using the minimum link length)
- Cell-size
  - **100 m x 100 m** square grid cells
  - Number of cells: Total 3,440,159
- Calibration period: 2016

❖ REDPOLL input data

Data	Description/properties	Source
Weather	Precipitation, temperature	Korea Meteorological Administration
Topography	Elevation, slope, flow direction, flow accumulation	National Geographic Information Institute
Land cover	Land cover classification	Land cover classification of the Ministry of Environment, USGS
Vegetation	Leaf Area Index (LAI)	Land cover classification of the Ministry of Environment
Soil	Soil moisture content, saturated hydraulic conductivity, soil porosity distribution index	Detailed soil map of National Institute of Agricultural Sciences
Aquifer	Baseflow attenuation coefficient	-
Point sources	Treated and untreated point-sources	Pollution source investigation data of the Ministry of Environment
River	National rivers, local streams, river/stream width and depth	National Geographic Information Institute
Watershed	Map of the TMDLMP watersheds	Ministry of Environment

Model Calibration

❖ **Flow rate calibration results**

- PBIAS (%): Average: **28.5%,**
  Max: 135.6%, Min: 0.4%
- calibration results are considered to be **fairly reasonable**

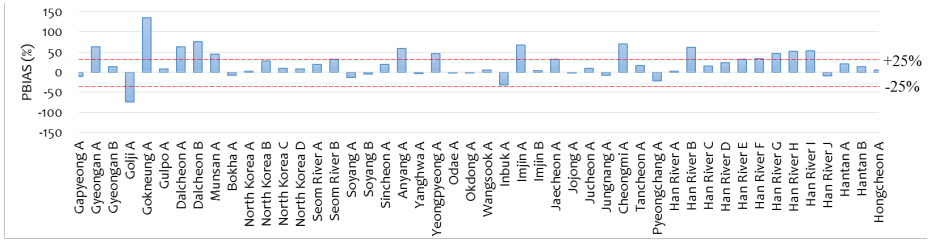
❖ **Water quality calibration results**

- Overall results are **satisfactory**

$$PBIAS = \frac{\left|\sum_{i=1}^{n} O_i - \sum_{i=1}^{n} P_i\right|}{\sum_{i=1}^{n} O_i} \times 100$$

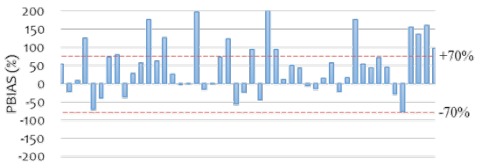
O_i = observed values
P_i = simulated values
n = total number of observations

<Flow rate>

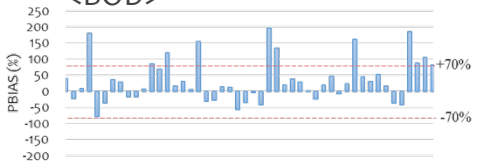


	SS	BOD	TN	TP
Maximum	201.0	143.0	153.4	196.5
Minimum	-76.9	-54.9	-44.6	-79.8
Average (Absolute value)	**66.8**	**30.5**	**21.0**	**53.2**
Rating(1)	Satisfactory	Good	Very good	Satisfactory

<SS>



<BOD>



<TN>

<TP>

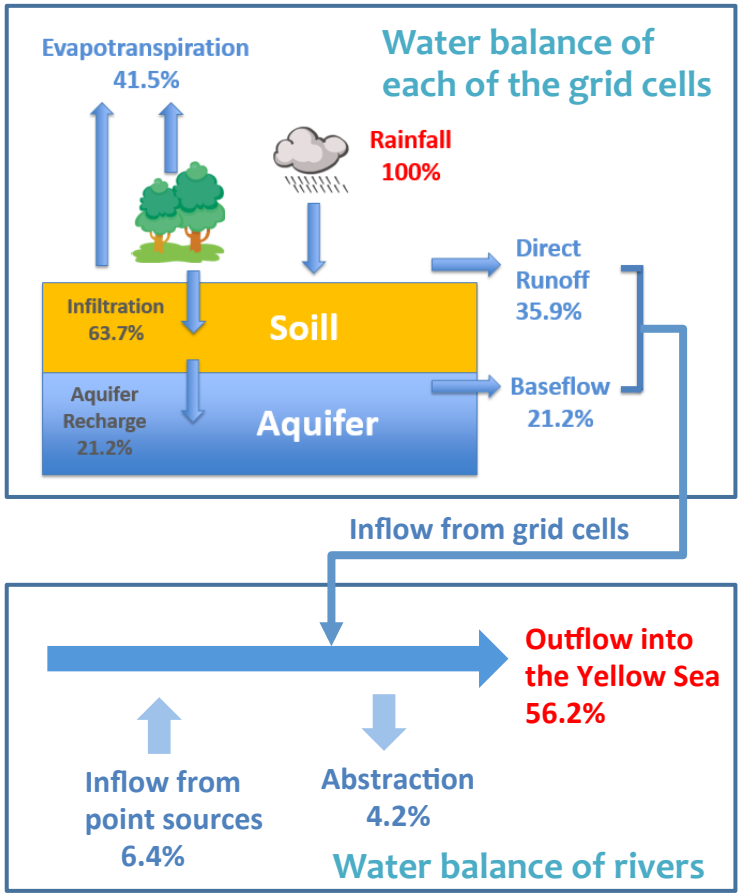
(1) Moriasi et al. (2007)

Water Balance

❖ Water balance for the Han River Watershed

- Simulation year 2016, 1 day interval simulation result

	Hydrological Processes	mm/year	%
Inflow	Precipitation	1100.6	100.0
	Discharge from point-sources	70.9	6.4
Outflow	**Evapotranspiration**	**456.4**	**41.5**
	Transpiration	(271.7)	(24.7)
	Soil evaporation	(181.2)	(16.5)
	Impervious surface	(3.5)	(0.3)
	Abstraction	45.8	4.2
	River flow to the Yellow Sea	**618.7**	**56.2**
	Direct runoff	(395.6)	(35.9)
	Baseflow	(233.6)	(21.2)
Storage change		50.5	4.7



Pollution loads to the Yellow Sea

❖ Monthly variation of pollution loads to the Yellow Sea

- Large variation due to monthly precipitation

Month	Precipitation		Flow		SS		BOD		TN		TP	
	(mm)	(%)	(10^9 m^3)	(%)	(10^3 ton)	(%)	(10^3 ton)	(%)	(10^3 ton)	(%)	(10^3 ton)	(%)
1	10.7	1.0	0.8	3.6	1.8	0.2	1.4	2.5	3.5	4.3	0.1	2.2
2	47.7	4.3	0.9	4.4	40.7	4.9	2.5	4.5	4.3	5.2	0.2	5.8
3	38.7	3.5	1.2	5.6	52.5	6.3	3.3	5.9	5.0	6.1	0.3	7.0
4	91.9	8.3	0.9	4.1	27.1	3.2	2.3	4.0	3.8	4.6	0.2	4.3
5	107.1	9.7	1.3	6.1	74.9	9.0	4.1	7.3	5.6	6.8	0.3	9.0
6	34.1	3.1	0.6	3.0	3.1	0.4	1.4	2.5	3.2	3.9	0.1	1.8
7	442.9	40.2	7.5	35.2	413.3	49.4	22.5	40.0	25.5	30.9	1.6	41.6
8	77.9	7.1	1.6	7.6	12.5	1.5	3.0	5.3	5.9	7.1	0.1	2.8
9	52.4	4.8	1.5	7.1	11.6	1.4	2.8	5.0	5.5	6.7	0.1	2.6
10	119.6	10.9	2.5	11.7	156.8	18.7	7.5	13.4	9.9	11.9	0.6	16.5
11	17.1	1.6	1.1	5.3	5.3	0.6	2.0	3.6	4.5	5.4	0.1	1.8
12	59.4	5.4	1.4	6.4	36.8	4.4	3.3	5.9	5.8	7.0	0.2	4.8
Total	1,100.6	100.0	21.3	100.0	836.5	100.0	56.1	100.0	82.5	100.0	3.8	100.0

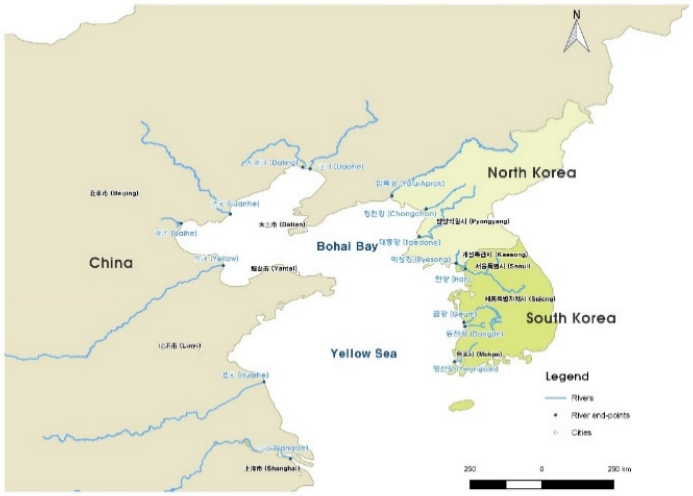
Pollution loads to the Yellow Sea

❖ Contribution assessment of pollution sources for effective watershed management

Sources	SS		BOD		TN		TP	
	(10^3 ton / year)	(%)	(10^3 ton / year)	(%)	(10^3 ton / year)	(%)	(10^3 ton / year)	(%)
Point source	6.9	0.2	10.5	13.2	27.1	24.8	0.8	7.3
Diffuse source	2,741.9	99.8	68.7	86.8	82.3	75.2	10.1	92.7
Direct runoff	(2,695.8)	(98.1)	(56.2)	(71.0)	(51.8)	(47.3)	(9.7)	(89.1)
Baseflow	(46.1)	(1.7)	(12.5)	(15.8)	(30.5)	(27.9)	(0.4)	(3.6)
Total discharge	2,748.8	100.0	79.2	100.0	109.4	100.0	10.9	100.0
Reduction by attenuation	1,912.2	69.6	23.1	29.1	26.8	24.5	7.1	65.2
Loads to the Yellow Sea	836.5	30.4	56.1	70.9	82.5	75.5	3.8	34.8

Summary

- ❖ Simulation of watershed model and estimation of pollution loads
  - **River flows and pollution loads have a wide range of daily and monthly variation**
  - Diffuse source pollution loads contribution ratio: **SS(99.8%), BOD(86.8%), TN(75.2%), TP(92.7%)**
- ❖ Future studies
  - Additional validation of result to enhance result credibility
  - Long-term (more than 10 years) simulation considering weather variations
- Suggestions
  - ❖ Only simulated the pollution loads from the Han River Watershed among the many other major rivers flowing into the Yellow Sea
  - ❖ Necessary to extend the geographical range
  - ❖ **Develop a common modeling platform among related countries**



Thank You

HydroCore

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