Toward Sustainable Groundwater in Agriculture – An International Conference Linking Science and Policy
28-30 June 2016
Burlingame / San Francisco, California
Organized by the University of California Davis & Water Education Foundation

United Nations Educational, Scientific and Cultural Organization
Sharif University of Technology
UNESCO Chair in Water and Environment Managment for Sustainable Cities

# PLANNING FOR SUSTAINABLE MANAGEMENT OF GROUNDWATER RESOURCES

CASE STUDY: NISHAPUR PLAIN IN IRAN

AHMAD ABRISHAMCHI
FAEZEH KHAKBAZAN



# Water Resources and uses in Iran

Arid-Semi Arid region, average annual Precipitation: 220 mm
Average annual precipitation volume= 417 bcm
Average annual E and ET = 299 bcm
about 72% of P
Surface water = 92 bcm; about 22% of P
Direct seepage to alluvial aquifers
= 25 bcm; about 6% of P
Annual Renewable Resources = 92+25=117 bcm
potentially accessible

Water uses
Agr: = 83.5 bcm = 92.5% of total water exploitation; 50% SW and 50% GW
Municipal: 5.4 bcm = 6% of total water exploitation; 68% GW, 32% SW



# Water Resources and uses in Iran

Water Resources, specially Groundwater, management is not sustainable.
More than 90% of groundwater basins are overexploited during the last 3 decades
Planning for Sustainable use of GW is vital for social and food security.



# Sustainability

- The concept of sustainability appeared in the early 1980s.
- Sustainability is a function of various economic, environmental, ecological, social, and physical goals.
- A fundamental aspect of sustainable development is the belief that future generations have a right to the same, if not better, economy, environment, and quality of life than we enjoy today .



# Sustainable Yield

- Sustainable yield is defined as the development and use of groundwater resources in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences.
- Sustainable yield cannot be simply calculated as a single value using the water balance; it requires assessing the dynamic response of the groundwater system to the introduced pumping regime and how this response affects the environment and society.

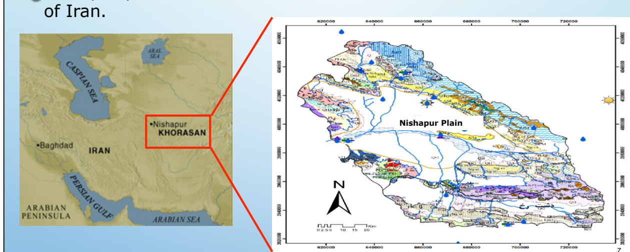


# Objectives

1- Estimating the regional groundwater sustainable yield in different scenarios
2- Estimating the required time to achieve groundwater sustainability in each scenario
3- Minimizing the adverse effects caused by the uncontrolled withdrawal of groundwater resources specially in dry years
4- Maximizing the benefits of the groundwater use for all stakeholders considering the groundwater sustainability
5- Enabling GW management to deal with the complexities and uncertainties using BBN

# Study Area

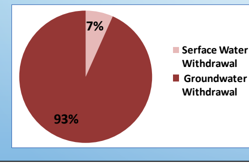
- Nishapur plain is located in Khorasan Razavi Province, in the north east of Iran.






# Study Area

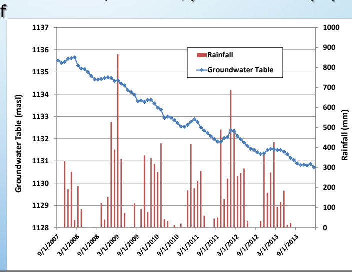
- Area of the Plain: about 6000 $Km^2$
- Average annual rainfall: 234 mm
- Annual evaporation: about 2300 mm
- **Groundwater** is the **main source** of water supply






# Study Area

The aquifer **unit hydrograph** shows a **decreasing trend** in groundwater level and storage. Water table drop of **1m/year** due to **population increase** and **expansion of Irrigated** lands
Causing drying up wells,
Deepening of the wells,
Land subsidence,…






# Methodology

Planning for sustainable management of groundwater resources is a **complex task** due to its **long-term nature** faced with many **uncertainties**.

**Numerical models** will be used to simulate GW system and several **management scenarios** will be examined to determine **Sustainable Groundwater Yield** using the concept of "**capture**".



# Methodology

Having determined the sustainable aquifer discharge in each scenario, **Game Theory** will be used to determine the **optimal groundwater resources allocation** to different consumers.
To consider the **effect of uncertainty** and participation of stakeholders in the sustainable management of groundwater resources, **Bayesian Belief Network** (BBN) will be used. **Hugin software** will be used for the development of BBN network structure based on the conceptual model of the study area.



# Capture Concept

- Under **pre-development** conditions, a groundwater system is in long-term equilibrium, and **recharge equals discharge**.

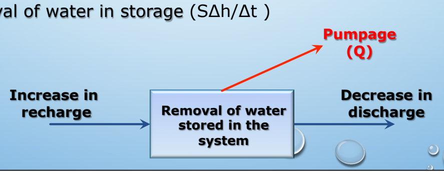
**Recharge** → **Groundwater System** → **Discharge**

**R=D** **(1)**

- R = virgin recharge
- D = virgin discharge

# Capture Concept

- When groundwater is withdrawn by pumping, this abstraction must be supplied by :
  - Increasing recharge ($\Delta R$)
  - Decreasing discharge ($\Delta D$)
  - Removal of water in storage ($S\Delta h/\Delta t$ )






# Capture Concept

Mass Balance Equation

$R + \Delta R = D + \Delta D + Q + S\,\Delta h/\Delta t$ **(2)**

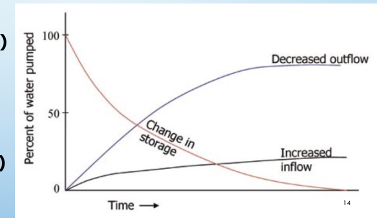
At new equilibrium

$S\,\Delta h/\Delta t = 0$ **(3)**

**(1), (2) and (3)**

$\Delta R = \Delta D + Q$ **or**

$Q = \Delta R - \Delta D$ **(4)**





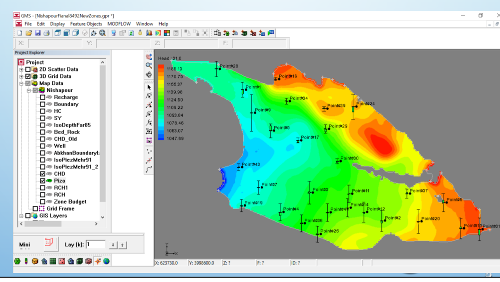

# Capture Concept

- The sum of the increase in recharge and decrease in discharge is referred to as capture (Equation 4)
- Equilibrium is reached only when pumping is balanced by capture.
- The most important implication of the capture principal is that virgin recharge does not determine sustainability.



# Numerical Model

- Groundwater model of Nishapur plain is developed using MODFLOW.





# Numerical Model

- Areal recharge rate is estimated as sum of the two components, 5% of average annual rainfall and 45% of the annual withdrawn water.
- Based on the available data, average annual GW withdrawals in the plain is about 507 MCM from which more than 88% is used in agriculture.
- Using MODFLOW, natural condition (pre-development condition) is simulated to estimate virgin recharge and discharge of the plain.
- Transient groundwater model of the Nishapur Plain is developed and calibrated (using PEST) for the 8 years period (Sep. 2005 to Sep. 2013).



# Results and Conclusion

## *Natural (pre-development) Condition*

| Water Balance Component | | Annual Rete (MCM) | |
|---|---|---|---|
| Rechareg | Groundwater Inflow | 41.30 | |
| | Areal Recharge | 27.69 | |
| | Total | 68.99 | Virgin Recharge |
| Discharge | Outflow to Drain | 51.96 | |
| | Groundwater Outflow | 17.03 | |
| | Total | 68.99 | Virgin Discharge |
| **Change of Storage** | | **0.00** | |

# Results and Conclusion

## *Developed Condition*

| Water Balance Component | | Annual Rete (MCM) |
|---|---|---|
| Rechareg | Groundwater Inflow | 48.89 |
| | Areal Rechareg | 226.86 |
| | Total | 275.75 |
| Discharge | Groundwatre Abstraction | 506.38 |
| | Groundwater Outflow | 21.38 |
| | Total | 527.76 |
| Change of Storage | | -252.01 |

reduction in groundwater storage

# Results and Conclusion

## *Groundwater Sustainable Yield*

| Water Balance Component | | Annual Rete (MCM) |
|---|---|---|
| Natural Condition | Virgin Recharge | 69.0 |
| | Virgin Discharge | 69.0 |
| Developed Condition | Groundwatre Recharge | 275.8 |
| | Groundwater Discharge | 21.4 |
| Sustainable Yield | | 254.4 |

# Results and Conclusion

## *Groundwater Sustainable Yield*

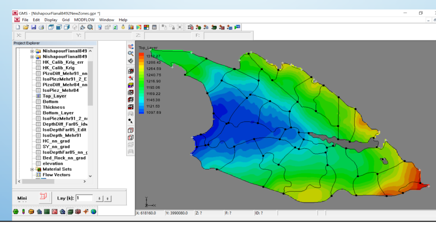
- Using capture concept, based on the average annual recharge and discharge derived from the **whole area of the plain**, groundwater sustainable yield is about **254 MCM** .
- Present **groundwater abstraction** is about **twice** the **sustainable yield**.
- The results show that by equating groundwater abstraction to sustainable yield, it takes about **100 years** to **reach a new equilibrium**.



# Results and Conclusion

## *Spatial Scale Effect*

- To consider local effects of GW pumping
- The area of the plain is divided into 32 zone, based on the distribution of pumping wells.





# Results and Conclusion

## *Groundwater Sustainable Yield*

- Based on the results:
  - 4 zones are sustainable in the current condition and pumping is equal to zero in the 9 zones.
  - Pumping is unsustainable in the 19 zones.
  - In this condition, **total sustainable yield** of Nishapur Palin is about **300 MCM**.
  - It takes about **75 years** to reach a new equilibrium in this condition.



# Results and Conclusion

## *Concluding Remarks*

- Based on the results, using **smaller spatial scale** :
  - Groundwater sustainable yield is **45 MCM greater** than sustainable yield derived from the whole area of the plain.
  - It takes **25 years less** than first condition to reach a new condition.

Spatial scale affects sustainable yield of the plain and it requires to examine different spatial scales to optimize sustainable yield and reduce required time to reach a new equilibrium.

## Future Works

- Examining Different Management Scenarios

Considering the conditions of the Nishapur plain, different management scenarios will be analyzed as follow:
-Changing crop pattern, increasing irrigation efficiency, and improving water productivity,
-Changing the temporal distribution of water use,
-Wastewater reuse,
-Artificial recharge of GW aquifers, and
-Controlling GW pumping.



## Future Works

- Examining different spatial and time scales to optimize sustainable yield
- Estimating required time to reach equilibrium relating to each sustainable yield
- Finding the optimum spatial and time scale

Spatial scale small enough to address important local impacts, but large enough to recognize the ability of aquifer system to adjust to pumping stress.

- Investigating the effects of uncertainties, (i.e., hydrogeological, demands,…) in management of water resources in order to maintain water security in critical conditions.



# Thank You!