How to maximize the predictive value of available data in ungauged basins?

Suxia Liu¹, *, Changming Liu¹, Weimin Zhao²

1. Key Laboratory of Water Cycle & Related Land Surface Processes, Institute of Geographic Sciences and Natural Resources Research, CAS, Beijing 100101, China;
2. The Bureau of Hydrology, Yellow River Conservancy Committee, Zhengzhou 450004, China

*liusx@igsnrr.ac.cn
Suxia Liu

Lake Donghu, Hubei
Luancheng, North China Plain

Akesu River, Xinjiang
Wuding River, Shaanxi

Niqu River, Sichuan
Lushi River, Henan

Wuxi, Jiangsu
Liangxi River

Gouburn River, NSW, Australia
Dawen River, Laiwu Shandong

Songhuang River, North East China
Yanghe, Hebei

Niqu River, Sichuan
Laiwu Shandong
Strengthen the hydrological theory

Extend the prediction of discharge to all the hydrological elements

Not only on the predictions of elements, but also on the Responses and among others

Not only hydrological, but also Interdisciplinary
China PUB Working Group

- Established in 2004
- Scientific Chair: Professor Academician Changming Liu
- Chair: Professor Jun Xia
- Vice Chair: Professor Dawen Yang, etc
- Secretary General: Professor Suxia Liu
Activities of China PUB so far
Activities of China PUB so far
IAHS-PUB-CHINA 2006

IAHS Publication No. 322 (RED book)

Activities of China PUB so far
Activities of China PUB so far
Activities of China PUB so far
• If there is no food at home, how will a house wife maximize the nutrition value of available food under the no-rice situations?
How? to maximize the predictive value of available data in ungauged basins?

• She will
  – **Borrow** (maps for interpolating & transplanting)
  – **Replace**—to find some substitutes
    • **From the same region**, (by modeling, rational; innovation ideas)
    • **From other regions**, (comparative analysis, paired-catchment and upscaling)
  – **Generate** (field and laboratory experiment)

*Liu et al. Advances in Geographical Science, 2010*
How? to maximize the predictive value of available data in ungauged basins?

(1) By borrowing

- Maps, annals of hydrological elements for interpolating and transplanting data from known regions
How to maximize the predictive value of available data in ungauged basins?
• Simple, but useful, usually for estimating annual runoff.
• Should and can be extended to all elements including evapotranspiration, soil moisture, etc.
• Hard to be sure in mountain areas, needs better interpolation method.
• GIS will enhance its applications
How to maximize the predictive value of available data in ungauged basins

(2.1) Replace _from the same region_

- By using **hydrological models**
How to maximize the predictive value of available data in ungauged basins
By Replacing from the same region

• **Simple** (conceptual model, rational formula, etc), or **complex model** (process-based model, eco-hydrological model, etc)?

Both have pro and cons but each plays important roles in different ways for PUB
How? to maximize the predictive value of available data in ungauged basins (2.1) Replace _from the same region

- Example By using HIMS model.
Components of HIMS:

HydroInformatic System Based on GIS

With the component-based GIS software (SuperMap), HIMS is able to manage the hydrologic database efficiently and derivate a watershed effectively.
Case study of the daily scale model in the Jinghe River Basin

Spatial patterns of runoff and runoff coefficient
Case study of Daily model in 331 watersheds of Australia

<table>
<thead>
<tr>
<th>Precipitation</th>
<th>&lt;400mm</th>
<th>400-600mm</th>
<th>600-800mm</th>
<th>800-1200mm</th>
<th>&gt;1200mm</th>
<th>mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area&lt; 100 km²</td>
<td>-</td>
<td>0.60</td>
<td>0.60</td>
<td>0.67</td>
<td>0.79</td>
<td>0.66</td>
</tr>
<tr>
<td>100-500 km²</td>
<td>0.56</td>
<td>0.51</td>
<td>0.78</td>
<td>0.78</td>
<td>0.84</td>
<td>0.73</td>
</tr>
<tr>
<td>500-1000 km²</td>
<td>-</td>
<td>0.52</td>
<td>0.70</td>
<td>0.81</td>
<td>0.69</td>
<td>0.68</td>
</tr>
<tr>
<td>&gt;1000 km²</td>
<td>-</td>
<td>0.25</td>
<td>0.80</td>
<td>0.81</td>
<td>0.75</td>
<td>0.65</td>
</tr>
<tr>
<td>Mean</td>
<td>0.56</td>
<td>0.47</td>
<td>0.72</td>
<td>0.76</td>
<td>0.77</td>
<td>0.68</td>
</tr>
</tbody>
</table>

- Dataset: 331 watersheds, 50 years daily precipitation and potential evaporation;
- Efficiency Coefficient: average to 0.68
Flood events prediction

♦ DEM resolution: 30-100m

♦ Temporal resolution: minutes to hours

Efficiency Coefficient > 0.8
The HIMS model, with good modeling behavior in different climate zone, shows high potential for regionalization, the potential to be used in ungauged basins.
How? to maximize the predictive value of available data in ungauged basins

(2.1) Replace _from the same region_

- Example by using VIP model.

![Diagram showing the process of input data A, model, and prediction and estimation B.]
VIP model

Mo et al. AEE, 2009
Features

- Three sources (sunlit and shaded canopy and soil surface) energy balance
- Variable storage runoff formation curve
- Vegetation ecological dynamic parameterization

Mo et al, AFM, 2001
Mo et al. MAP, 2004
Mo et al. EM, 2005
Mo et al. AEE, 2009
Wuding River
Model Output
径流 \( (m^3/s) \)
Model Validation
Model Validation

\[ Y = \frac{(Q_{\text{Sim}} - Q_{\text{obs}})}{Q_{\text{obs}}} \]
Model Validation

Annual scale
Model Validation
Model Validation

![Graph showing relative soil moisture (SM) for Suide and Yulin over different years and months, with VIP, TUW, and OBS lines indicated.](image-url)
Model Validation

![Graph showing model validation with Relative SM (%) on the y-axis and Mon on the x-axis, with two lines representing tuw and VIP_normalize.]
Model applications—generate long-term data series for future trend

North Drying,
Model applications----generate long-term data series for future trend

<table>
<thead>
<tr>
<th>Var.</th>
<th>Original time scale</th>
<th>Linear trend</th>
<th>Standardized time scale</th>
<th>Sig.</th>
<th>Lag-1 cor</th>
<th>The final estimate of trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
<td>(7)</td>
</tr>
<tr>
<td>P</td>
<td>-0.2886</td>
<td>-0.021</td>
<td>d</td>
<td>-0.15</td>
<td>-1.715</td>
<td>d</td>
</tr>
<tr>
<td>Rm</td>
<td>-0.0972</td>
<td>-0.007</td>
<td>c</td>
<td>-0.06</td>
<td>-1.031</td>
<td>c</td>
</tr>
<tr>
<td>ET</td>
<td>-0.2378</td>
<td>-0.017</td>
<td>c</td>
<td>0.295</td>
<td>-1.027</td>
<td>c</td>
</tr>
<tr>
<td>EC</td>
<td>-0.0897</td>
<td>-0.006</td>
<td>c</td>
<td>0.124</td>
<td>-0.418</td>
<td>c</td>
</tr>
<tr>
<td>ES</td>
<td>-0.3462</td>
<td>-0.025</td>
<td>c</td>
<td>0.411</td>
<td>-2.219</td>
<td>c</td>
</tr>
<tr>
<td>EI</td>
<td>0.0072</td>
<td>0.0005</td>
<td>b</td>
<td>-0.41</td>
<td>0.367</td>
<td>b</td>
</tr>
<tr>
<td>GPP</td>
<td>0.4381</td>
<td>0.0313</td>
<td>b</td>
<td>0.074</td>
<td>3.102</td>
<td>b</td>
</tr>
<tr>
<td>NPP</td>
<td>0.0837</td>
<td>0.006</td>
<td>b</td>
<td>-0.23</td>
<td>0.649</td>
<td>b</td>
</tr>
<tr>
<td>Runoff</td>
<td>-0.4345</td>
<td>-0.031</td>
<td>b</td>
<td>0.076</td>
<td>-3.333</td>
<td>a</td>
</tr>
<tr>
<td>( \theta_2 )</td>
<td>-0.3877</td>
<td>-0.028</td>
<td>c</td>
<td>0.204</td>
<td>-2.826</td>
<td>b</td>
</tr>
<tr>
<td>T</td>
<td>0.546</td>
<td>0.039</td>
<td>a</td>
<td>0.423</td>
<td>3.081</td>
<td>b</td>
</tr>
</tbody>
</table>

\( a \) if trend/correlation at \( \alpha=0.001 \) level of significance, for correlation coefficient, lower bound=0.49, upper bound=0.45
\( b \) if trend/correlation at \( \alpha=0.01 \) level of significance, for correlation coefficient, lower bound=0.39, upper bound=0.35
\( c \) if trend/correlation at \( \alpha=0.05 \) level of significance, for correlation coefficient, lower bound=0.30, upper bound=0.25
\( d \) if trend/correlation at \( \alpha=0.1 \) level of significance, for correlation coefficient, lower bound=0.26, upper bound=0.22

**SM decrease at 0.01;**  
**Discharge decrease at 0.001;**  
**P decrease at 0.1,**  
**T increases at 0.01**
Model applications---explore the response of hydrological elements to LUCC

<table>
<thead>
<tr>
<th></th>
<th>Net Radiation</th>
<th>Evaporation</th>
<th>Transpiration</th>
<th>Evaporation</th>
<th>Canopy interception</th>
<th>Surface runoff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmland</td>
<td>0.0</td>
<td>-0.22</td>
<td>-23.7</td>
<td>24.7</td>
<td>-59.4</td>
<td>1.8</td>
</tr>
<tr>
<td>Irrigated</td>
<td>1.8</td>
<td>-0.02</td>
<td>23.2</td>
<td>-21.5</td>
<td>84.6</td>
<td>0.2</td>
</tr>
<tr>
<td>Needle Forest</td>
<td>5.4</td>
<td>-0.01</td>
<td>22.8</td>
<td>-21.1</td>
<td>84.6</td>
<td>0.1</td>
</tr>
<tr>
<td>Deciduous</td>
<td>9.2</td>
<td>0.71</td>
<td>30.5</td>
<td>-29.7</td>
<td>247.4</td>
<td>-5.6</td>
</tr>
<tr>
<td>Mixed Forest</td>
<td>2.6</td>
<td>0.26</td>
<td>-15.7</td>
<td>18.1</td>
<td>-54.2</td>
<td>-2.1</td>
</tr>
<tr>
<td>Grassland</td>
<td>-0.3</td>
<td>0.20</td>
<td>14.9</td>
<td>-12.2</td>
<td>23.4</td>
<td>-1.6</td>
</tr>
<tr>
<td>Desert</td>
<td>-1.1</td>
<td>-16.87</td>
<td>-100.0</td>
<td>64.2</td>
<td>-100.0</td>
<td>134.5</td>
</tr>
</tbody>
</table>
Model applications----explore the response of hydrological elements to climate change

<table>
<thead>
<tr>
<th>dT, dP</th>
<th>C</th>
<th>L</th>
<th>Q</th>
<th>H</th>
<th>S</th>
<th>D</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>+0.5k, +10%</td>
<td>0.19</td>
<td>0.15</td>
<td>0.13</td>
<td>0.16</td>
<td>0.15</td>
<td>0.18</td>
<td>0.19</td>
</tr>
<tr>
<td>+0.5k, -10%</td>
<td>-0.20</td>
<td>-0.15</td>
<td>-0.13</td>
<td>-0.16</td>
<td>-0.17</td>
<td>-0.17</td>
<td>-0.20</td>
</tr>
</tbody>
</table>

- Response exists spatial variability。
- Response to precipitation is proportional
- When p increases, the response will be larger with the temperature gain
- When p decreases, the response will be smaller with the temperature gain
1km Rule,
1km Rule,

Uncertainty

The VIP model, although in very detail, but no need for calibration, can catch the mechanisms of the response for ungauged basin, which is useful to provide scientific basis for decision makers for water-saving agriculture, making reasonable adaptation measures to climate change and land-use/cover change. (explain why, tell how)
How? to maximize the predictive value of available data in ungauged basins

(2.1) Replace _from the same region

• By using rational formula (model)
\[ Q_m = 0.278 LF P (1 - R S e^{-r}) t_Q^{-n'} \]

\[ t_Q = P_1 x Q_m^{-y} \]

\[ n' = \frac{r P_1 (1 - P_1)^{r-1}}{1 - (1 - P_1)^r} \]

\[ P = \frac{f}{F} = 1 = (1 - \frac{t}{\tau})^r \]

\[ P_1 = \frac{t}{\tau} \]

\[ \tau = \frac{0.278 L_2^{0.5} F^{0.5}}{A_2 I_2^{0.33} Q_m^{0.5}} + \frac{0.278 L_1}{A_1 I_1^{0.35} Q_m^{0.3}} \]

\[ x = k_1 + 0.95k_2 \]

\[ y = 0.5 \left[ 1 - \log \frac{3.12(k_1/k_2) + 1}{1.246(k_1/k_2) + 1} \right] \]

\[ k_2 = \frac{0.278 L_2^{0.5} F^{0.5}}{A_2 I_2^{0.33}} \]

\[ k_1 = \frac{0.278 L_1}{A_1 I_1^{0.35}} \]

\[ \tau = k_2 Q_m^{-0.5} + k_1 Q_m^{-0.3} \]

\[ r = 2.1(k_1 + k_2)^{-0.06} \]
The Estimation of Small-Watershed Peak Flows in China

LIU CHANGMING AND WANG GUANGTE

Institute of Geography, Academia Sinica, Beijing, People's Republic of China

A small-watershed model based on the analysis of data measured from a number of small experimental watersheds and various physical geographic factors in our country is formulated for predicting the flood peak discharge resulting from storm rainfall. As the relevant factors and field measurements cover a wide range of conditions, this method is now being widely used for railway design works in the northwest and for hydraulic engineering design in certain other regions in China with fairly good results.

INTRODUCTION

China has a vast territory with innumerable streams. It is impossible to set up hydrometric stations to measure all their discharges. Nevertheless, a large number of new structures are to be built across these ungauged streams each year. To safeguard against flood damage, the evaluation of the flood peak discharge according to the physical geographic conditions of their watersheds becomes an important task to us.

So far as the formation of runoff is concerned, the process of stream runoff in watersheds may be regarded as the combination of two component parts, the processes of overland flow and channel flow. Obviously, these processes are relevant to a number of geographic factors and their distribution in space. Precipitation on the southeastern coast is about 1000 mm, while that in the northwestern interior is less than 100 mm. However, in contrast, storm rainfall intensity of short duration is much greater in the north than in the south. For example, the greatest intensity rainfall in 5 min is 53.1 mm, appeared in the western part of Taiyuan Shi of Shanxi province, while that on the southeastern coast is only 35 mm (in Jin-Jiang Xian of Fujian province). These statistics present a brief sketch of the regional distribution of storm rainfall in China.

As to the influence of terrain conditions on runoff, vegetation cover in the northwestern region is very sparse, the capability of surface storage and regulation is small, the velocity of concentration or travel of overland flow is comparatively fas-
The above rational formulae have been successfully used in designing the culvert and bridge construction along the 8 important railways in western ungauged area of China.
How? to maximize the predictive value of available data in ungauged basins
(2.1) Replace _from the same region

- Example by using innovational ideas(model)
Eco-hydraulic Radius method, Liu et al. 2008, Progress in Natural Sciences

LIHAFOLOVA method, Liu et al. 2008, NSDBYSLKJ,

Relation between Amphibians and flow regimes, Liu et al. GWSP newsletter, 2008,

The above new methods were successfully used in western ungauged area of China for decisions-makers for planning the project to transfer water from South to North.
How to maximize the predictive value of available data in ungauged basins (2.2) Replace from the other region

- Comparative analysis

- or
Comparative Hydrology (CH)

- Brankov (1946)
- Chapman, T, G, Philosophy and analytical approaches, Section 1, Comparative Hydrology, draft 2, June 1986
- 1986, IHP_III, CH workshop
- Ming-Ko Woo, Changming Liu, Mountain hydrology of Canada and China: A case study in comparative hydrology Hydrological Processes, 8(6)573-587, 1994

\[ R_x = \frac{R_0 P_x}{P_0} \]
Comparative Hydrology (CH)


关于比较水文学的研究

刘昌明
(中国科学院地理研究所)

提 要

比较水文学是水文研究中的新课题。作者根据国际水文计划 (IHP) 组织的研究活动介绍了这一课题最新动向；探讨了比较水文的概念，目的与研究方法；提出在我国开展这一研究的有利条件。认为及早起步开展工作，可望走在世界前列；最后建议从水文类型系统、水文过程、水文实验方面打好基础，建立比较水文信息，发展水文成因模型，制定应用方案。

二、研究内容

水文学中的比较研究的方法并不年轻，从文献上看，狭义的比较水文方法有较早的历史：人们利用相似流域或参证流域来估算无观测资料流域的正常径流已有半个世纪左右的时间，如维尔德（Вейлд）的方法。布兰科夫[1]1946年发表的“水文分析与计算”，认为自然地理条件相似的河流，可假定它们的径流系数相近，由具有实测资料流域的正常径流 $R_s$ 作为参证，估算无实测资料流域的正常径流 $R_1$。
Significance in Comparative Hydrology is to provide a base for understanding the dissimilarity and similarity in runoff formation of gauged and ungauged basins that is needed for deduction of the hydrological processes.
paired-catchment analysis

Liu et al. MAP, 2004
How? to maximize the predictive value of available data in ungauged basins

(3) Generate

- Field and laboratory experiments, remote sensing
Field survey and artificial rainfall-runoff experiments
Field survey and artificial rainfall-runoff experiments over many different basins.
Remote Sensing

Data Assimilation

VIP model

In-situ

Long-term soil moisture data

Liu et al. HESS, 2009
Some more to be done in the near future

- Strengthen PUB theoretical study: now more in skill; theory in regional hydrology, comparative hydrology, PUB theoretical framework, in-situ experiments and general models, are highly wanted.
Some more to be done in the near future

Aim for innovative methods: Now all the methods are still in the general framework of the methodology
Some more to be done in the near future

- Find more applications of PUB. Now more in theoretical study, few on the practical problem solving
Thank you!
Welcome your comments.....

How to maximize the predictive value of available data in ungauged basins?

By
Suxia Liu, Changming Liu and Weimin Zhao