# 参数评估和不确定分析

## 嵌套模型使用PEST++ (ver.5.0)

历史匹配方法的细节参考Corson-Dosch (2022)，实施历史匹配，为嵌套模型和LGR模型细化参数评估，使用与区域模型相同的观测数据。

嵌套模型使用PEST++ (ver.5.0) (White et al., 2021)，定量参数评估的不确定性，在可接受的测量值范围内复演模拟的水头和河流径流。

# 迭代系综光滑方法和不确定度定量化

iES是一种系综方法，意思是在分析的每个阶段，生成参数集的系综（或realization），与内在的不确定度和观测数据的假设不确定度一致。然后，使用从该系综得到的各参数集实施模拟，产生模型输出的一个范围。iES使用参数和观测系综之间的经验关系，迭代降低不确定度以及模拟和实测之间差异，提供一个反映参数的内在不确定度的后验参数系综。一次"base-case"实现表征最小的误差方差解，当模拟时需要一套参数值时使用。使用该"base-case"实现用于场景测试。

# 观测数据

表2和表3罗列了使用的观测数据和观测权重（Pleasant Lake and Plainfield Tunnel Channel Lake）

观测水位和径流在月末时分配值。

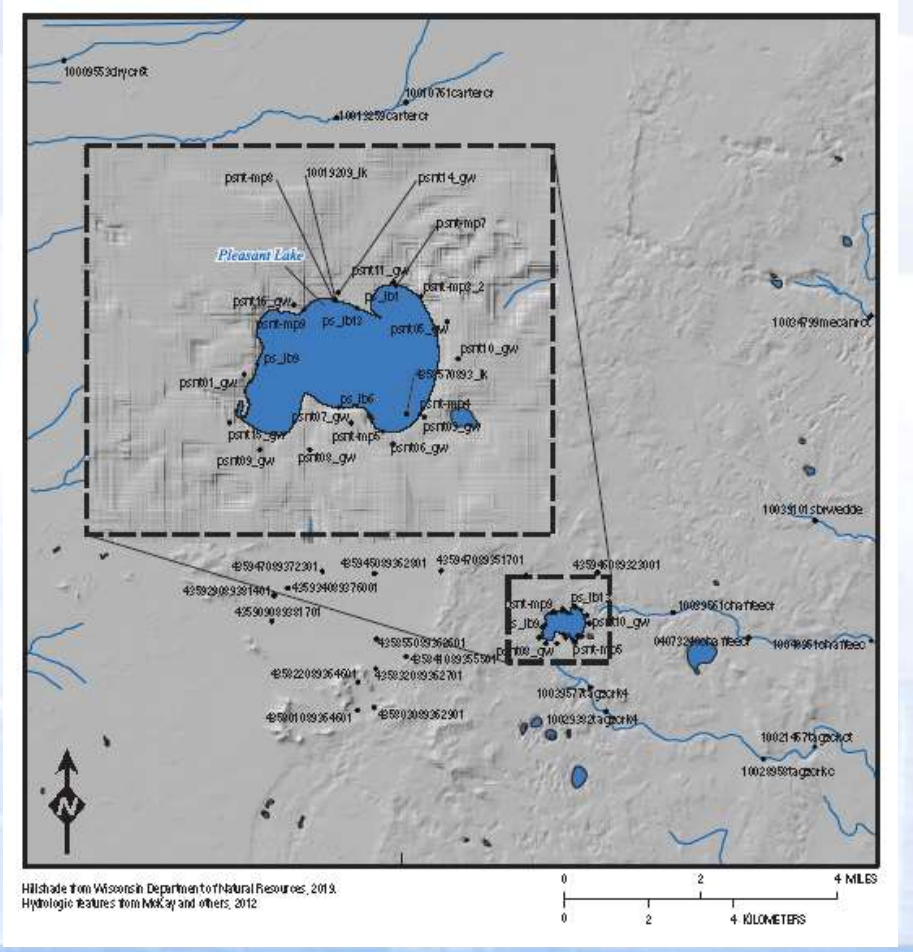
**Table 2.** Observation data groups, values, and descriptions for Pleasant Lake inset model, Central Sands region, central Wisconsin.

[PEST, parameter estimation package; WGNHS, Wisconsin Geological and Natural History Survey; NA, not applicable; USGS, U.S. Geological Survey; NWIS, National Water Information System database; WDNR, Wisconsin Department of Natural Resources]

| Group name in the PEST files | Observed values | Target type | Description | Total number of observations | Number of weighted observations | Number of zero-weighted observations | Weight | Weight-informed standard deviation | Data source |
|---|---|---|---|---|---|---|---|---|---|
| hds_wgnhs_tr; heads_wgnhs | 280.311 to 327.17 | Hydraulic head | Well-construction report that includes groundwater elevation measured after a well was drilled. Locations were determined by the WGNHS. | 100 | 0 | 100 | 0 | NA | WDNR, 2022 |
| nwis_dvs | 298.00 to 314.72 | Hydraulic head | Groundwater elevations at locations with daily data collected by USGS. | 14 | 14 | 0 | 3.78 to 7.13 | 0.14 to 0.26 | USGS, 2021 |
| nwis_fm | 264.09 to 300.84 | Hydraulic head | Groundwater elevations at miscellaneous locations measured by USGS. | 2 | 0 | 2 | 0 | NA | USGS, 2021 |
| nwisdvs_tr | 297.75 to 315.47 | Hydraulic head | Groundwater elevations at locations with daily data collected by USGS. | 133 | 133 | 0 | 1.26 to 2.04 | 0.49 to 0.79 | USGS, 2021 |

# 观测数据

水位观测的位置（2个湖泊）见图21和图22. 标记对应观测名称，用于PEST++输入文件。



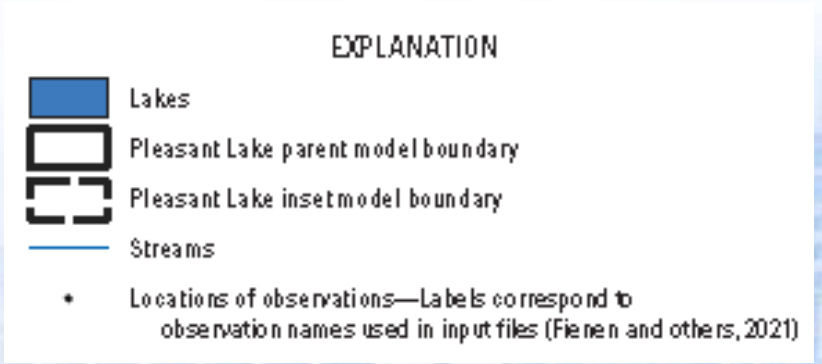




图21 水位观测位置

# 参数化

嵌套模型的参数化策略是对大多数参数实施乘子，到可能的取值范围。

嵌套模型的初始参数值可得到从区域模型历史匹配的模拟结果。

表4和表5罗列了2个湖泊的参数化。

**Table 4.** Parameter groups, values, and descriptions for Pleasant Lake inset model, Central Sands region, central Wisconsin.

[PEST, parameter estimation package; *K*, hydraulic conductivity; SFR, Streamflow Routing package]

| Group name in the PEST files | Group description | Transform | Count | Initial value | Lower bound | Upper bound |
|---|---|---|---|---|---|---|
| _k33_pp_inset:0 | Inset vertical *K* pilot point multipliers: layer 1 | log | 99 | 1.00 | 0.01 | 10.00 |
| _k33_pp_inset:1 | Inset vertical K pilot point multipliers: layer 2 | log | 99 | 1.00 | 0.01 | 10.00 |
| _k33_pp_inset:2 | Inset vertical *K* pilot point multipliers: layer 3 | log | 99 | 1.00 | 0.01 | 10.00 |
| _k33_pp_inset:3 | Inset vertical *K* pilot point multipliers: layer 4 | log | 99 | 1.00 | 0.01 | 10.00 |
| _k33_pp_inset:4 | Inset vertical *K* pilot point multipliers: layer 5 | log | 99 | 1.00 | 0.01 | 10.00 |
| _k33_pp_parent:0 | Parent vertical *K* pilot point multipliers: layer 1 | log | 81 | 1.00 | 0.01 | 10.00 |
| _k33_pp_parent:1 | Parent vertical *K* pilot point multipliers: layer 2 | log | 81 | 1.00 | 0.01 | 10.00 |
| _k33_pp_parent:2 | Parent vertical *K* pilot point multipliers: layer 3 | log | 81 | 1.00 | 0.01 | 10.00 |

# 历史匹配结果

系综方法得到多次迭代的目标函数值的系综（Pleasant湖的嵌套模型见图23）。

蓝色线表示基础系综实现，青灰色表示所有其他系综实现的轨迹（图23）

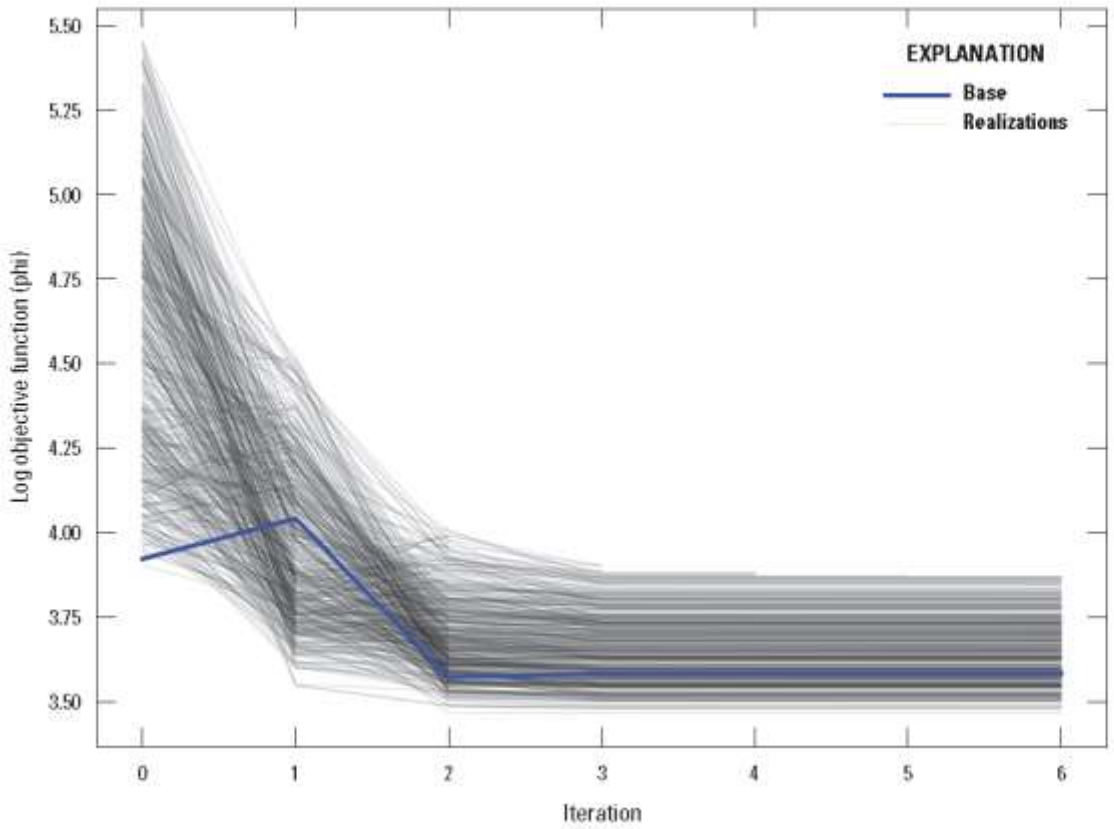
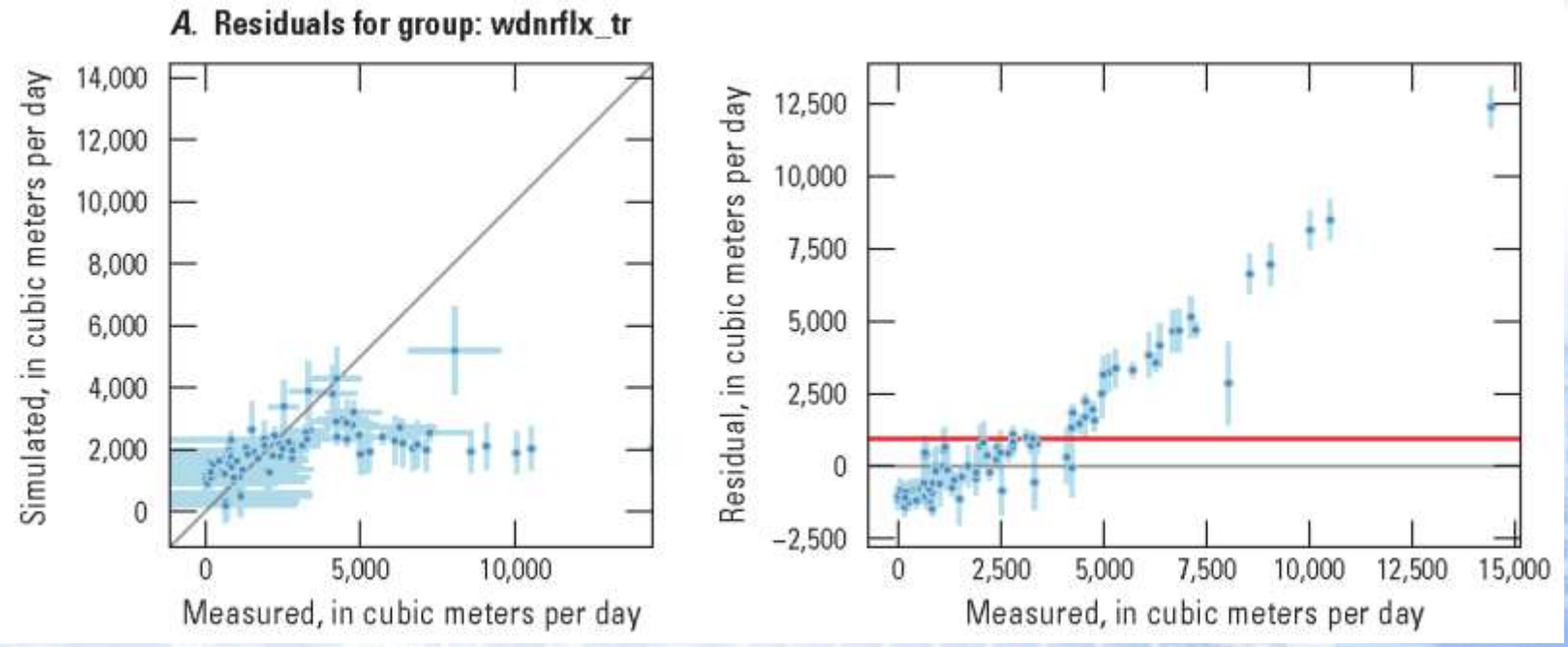



**Figure 23.** Summary of ensemble realization and base objective function progress by iterative ensemble smoother (iES) history matching algorithm iteration for Pleasant Lake inset model, Central Sands region, central Wisconsin.

各测点的地下水头（还有其他变量，MODFLOW6的约定变量）的实测值与计算值对比



# 嵌套模型的实测值与计算值的残差分布图

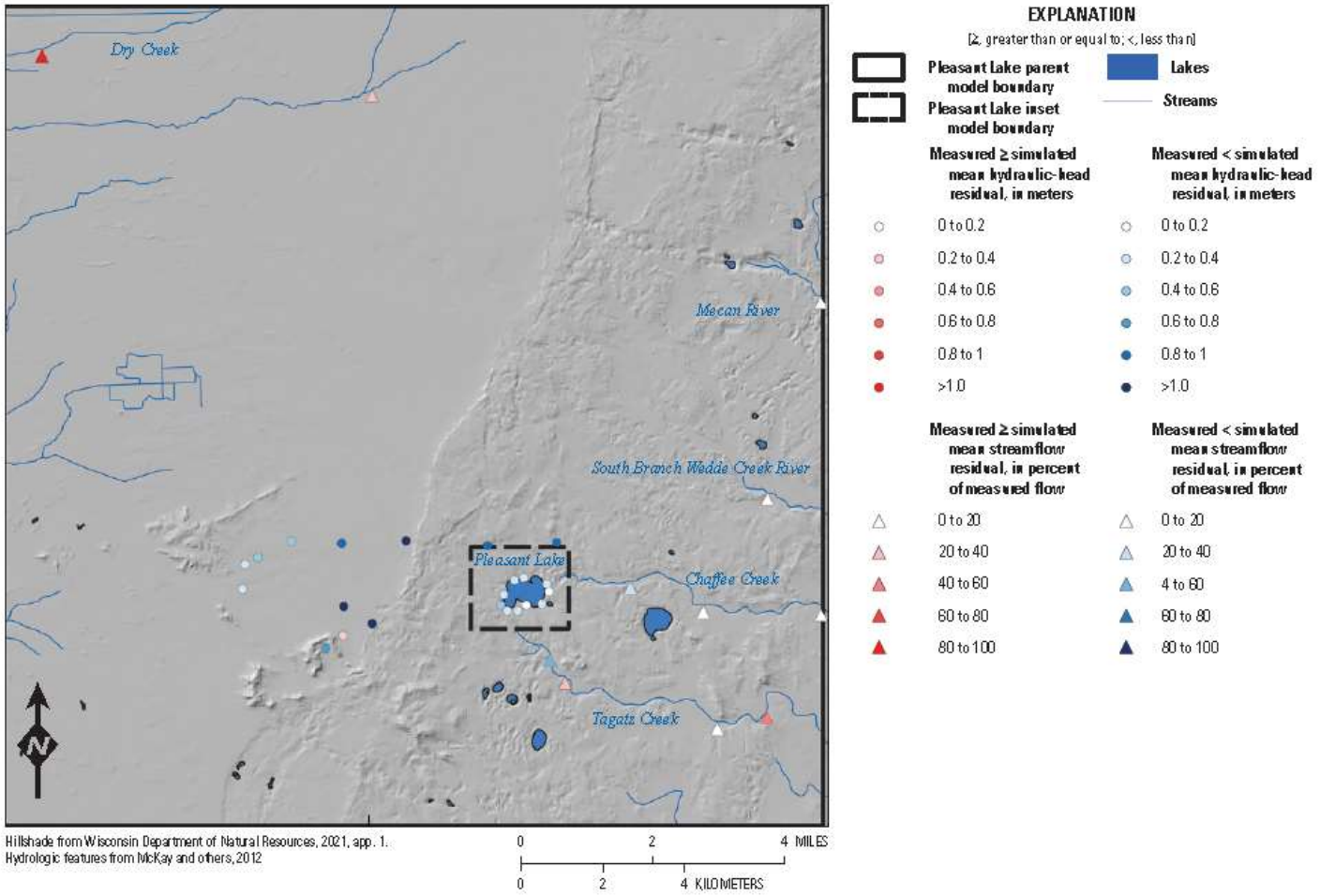



**Figure 40.** Spatial pattern of mean fit between measured and simulated observations for Pleasant Lake inset model, Central Sands region, central Wisconsin.

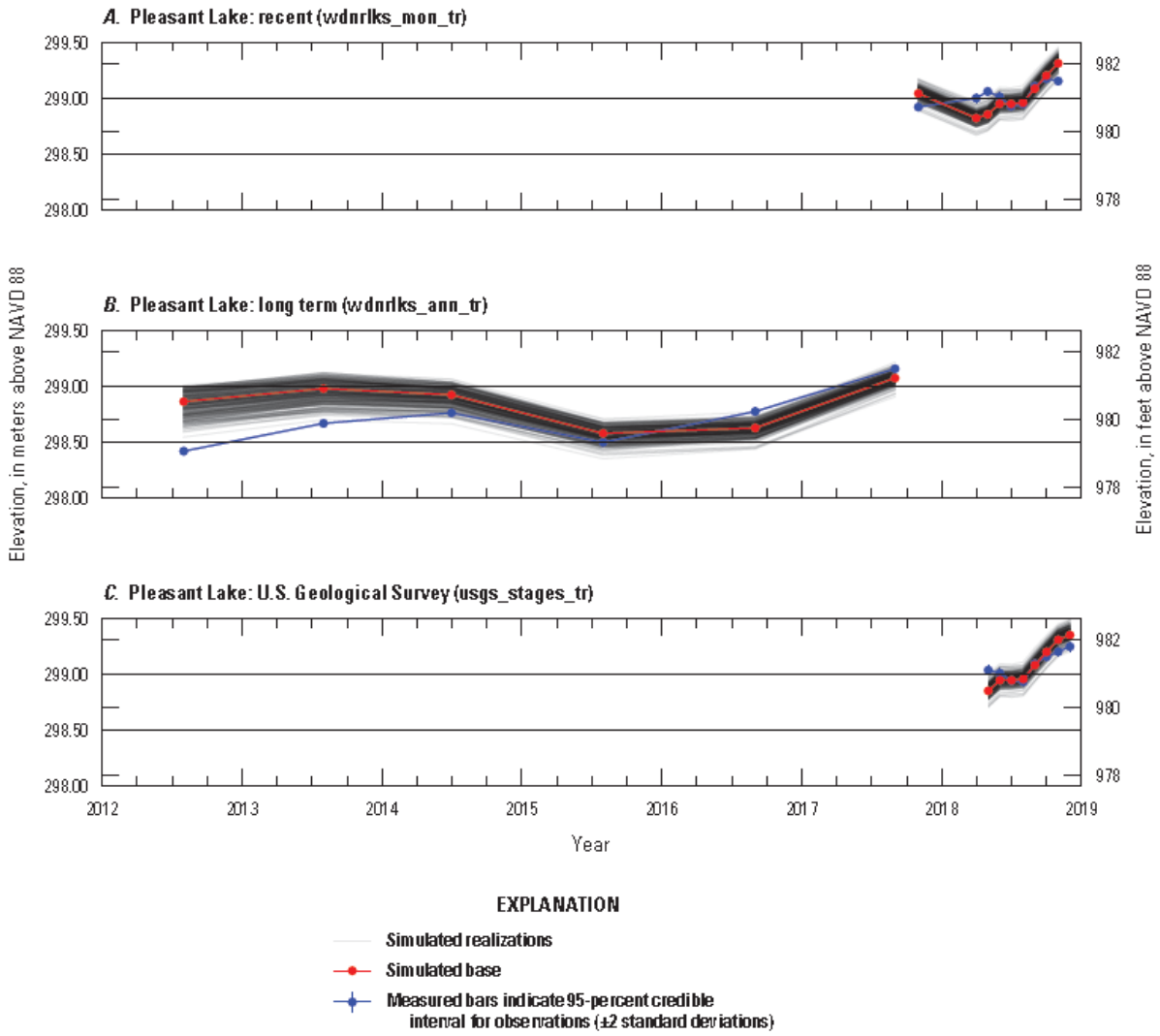
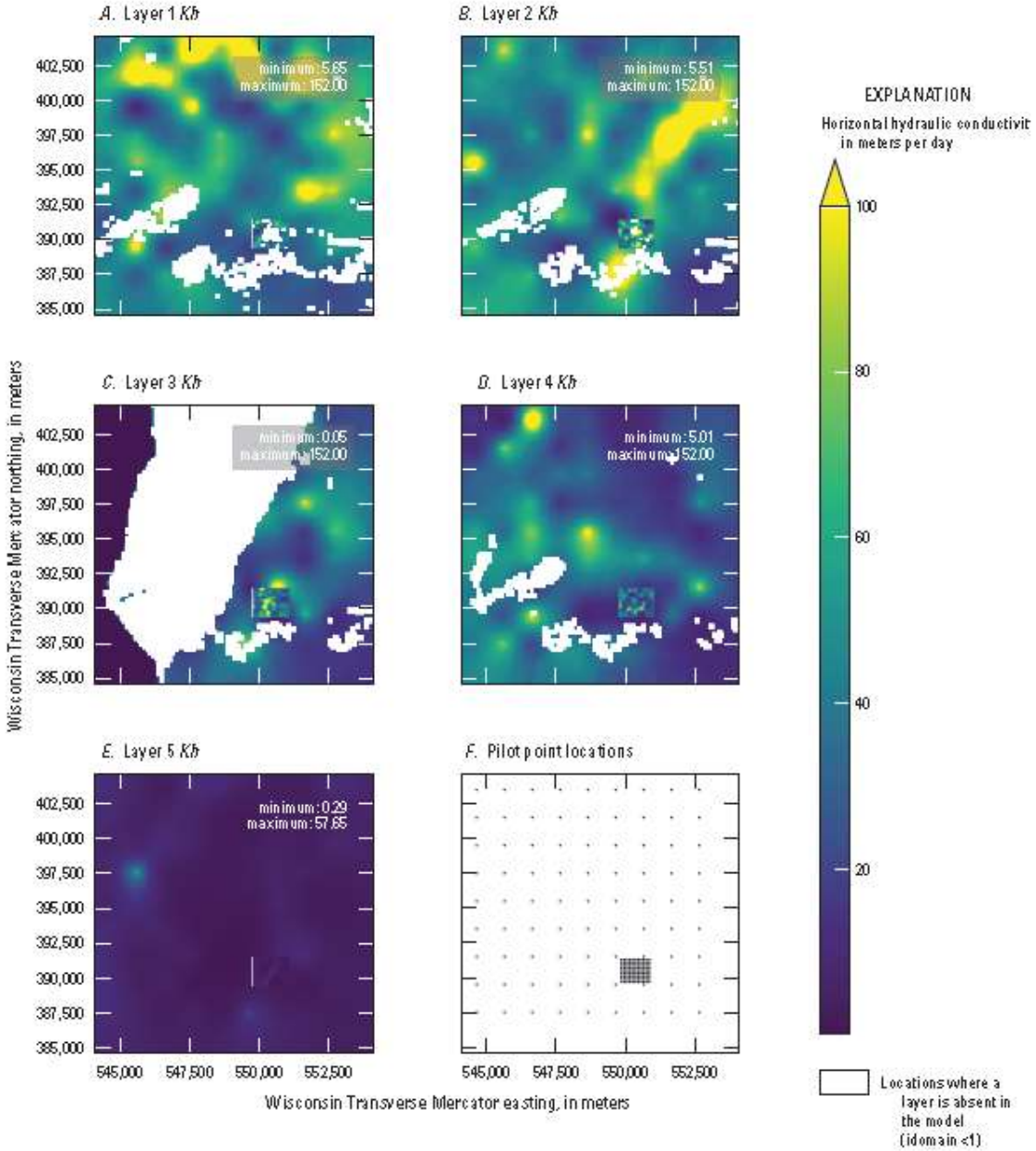
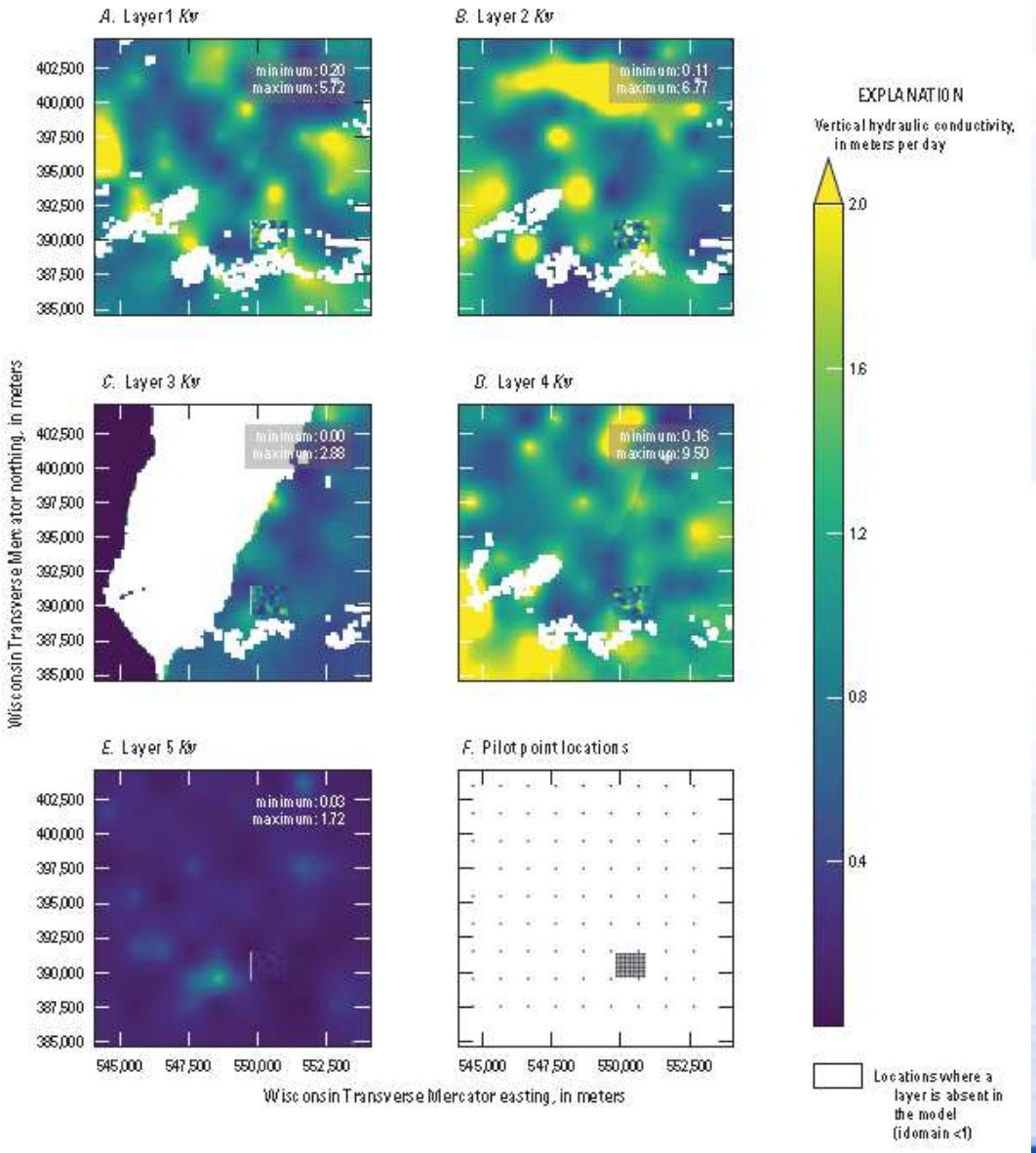



**Figure 42.** Time series of measured and simulated results for lake level observations in the Pleasant Lake inset model, Central Sands region, central Wisconsin: *A*, observation group wdnrlks_mon_tr; *B*, observation group wdnrlks_ann_tr; and *C*, observation group usgs_stages_tr. The observation group names are defined in table 2.

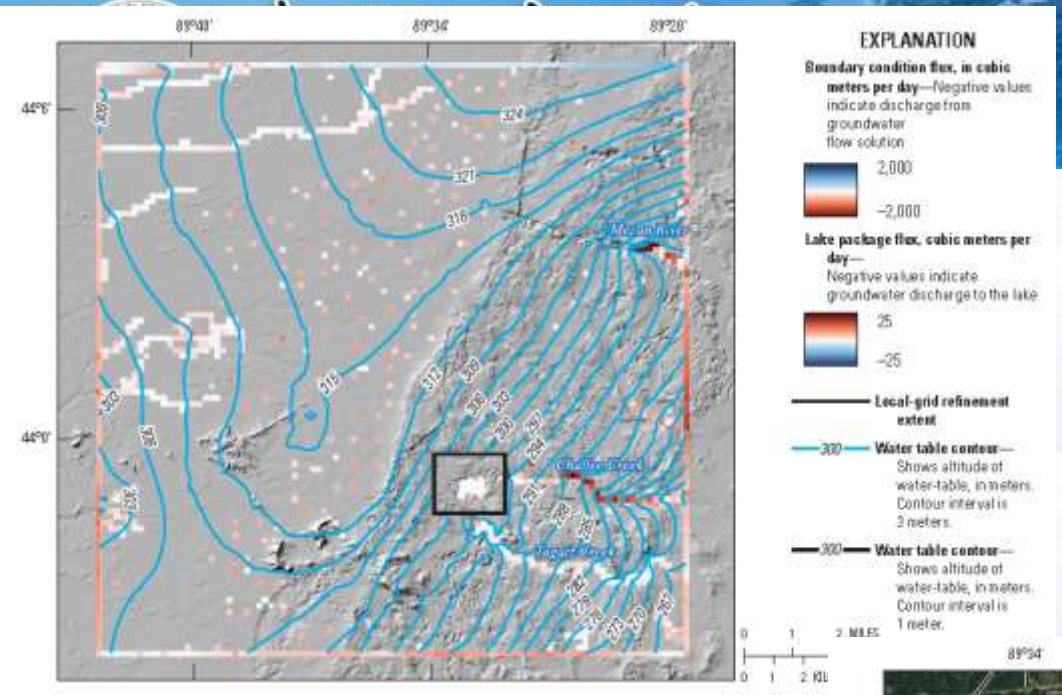


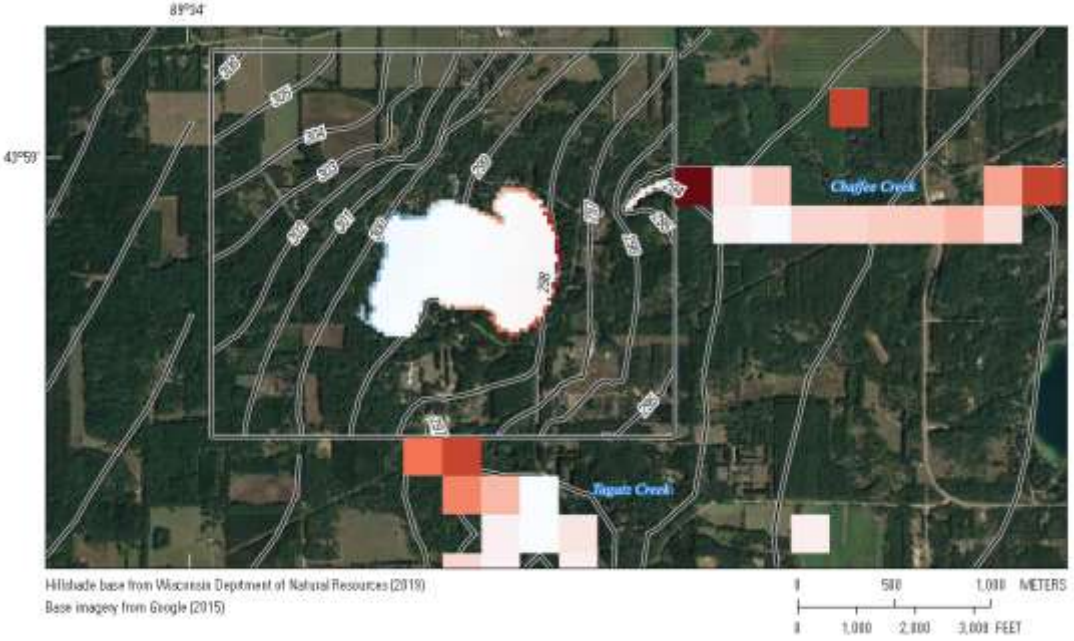

Pleasant湖嵌套模型的水平向水力传导度的评估值（各分层上的分布）



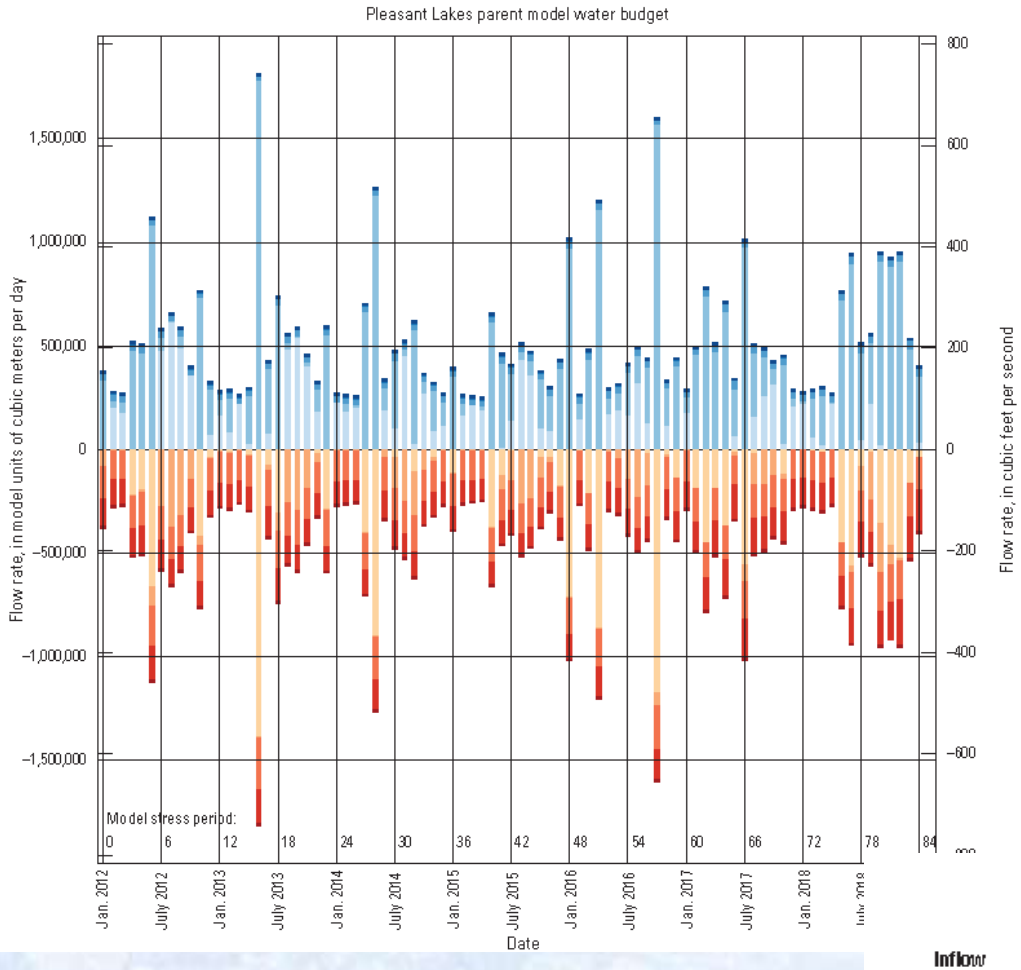

Pleasant湖嵌套模型的垂向水力传导度的评估值（各分层上的分布）

还有，Ss与Sy的分布图




Pleasant湖模型的地下水位和边界通量

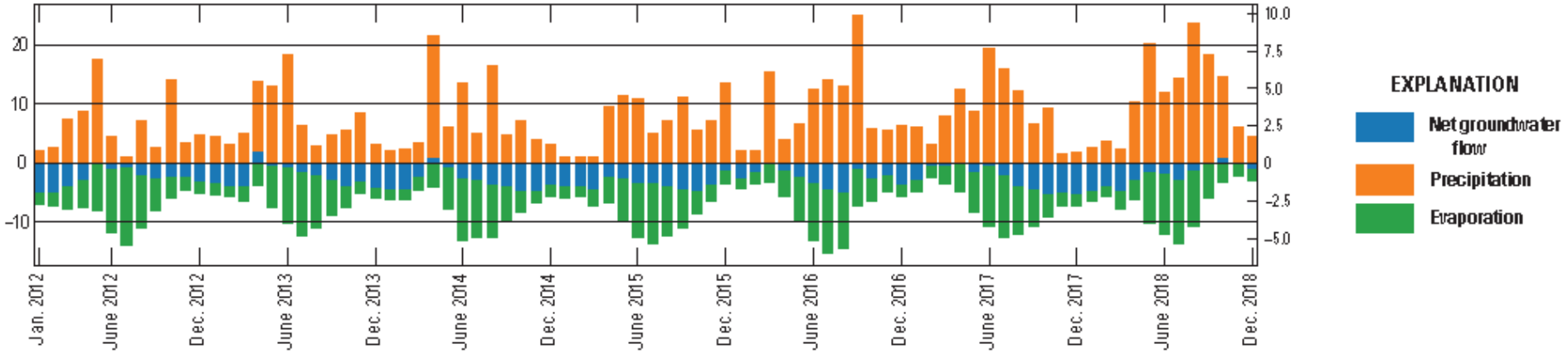



**EXPLANATION**

[Inflow and outflow are relative to the parent model groundwater system; LGR, local grid refinement]

| Inflow | Outflow |
|---|---|
| Specific storage (STO-SS_IN) | Specific storage (STO-SS_OUT) |
| Specific yield (STO-SY_IN) | Specific yield (STO-SY_OUT) |
| Recharge package (RCH_IN) | Recharge package (RCH_OUT) |
| Constant head package (CHD_IN) | Constant head package (CHD_OUT) |
| Streamflow routing package (SFR_IN) | Streamflow routing package (SFR_OUT) |
| Flow between the LGR parent and inset model (FLOW-JA-FACE_IN) | Flow between the LGR parent and inset model (FLOW-JA-FACE_OUT) |

*C.* Pleasant Lake budget




**gure 71.** Lake model-simulated water budgets for *A*, Plainfield; *B*, Long; and *C* Pleasant Lakes, Central Sands region, central Wisconsin.

地下水对农业灌溉和生态补水的响应分析，。。。