Quality Assurance Project Plan

Modeling the Impact of Hydraulic Fracturing on Water Resources Based on Water Acquisition Scenarios

Prepared for:

U.S. Environmental Protection Agency
Office of Research and Development

Prepared by:

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In conjunction with subcontractors:

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Texas A&M University

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Section A – Project Management

A1 Approval Page

Signatures indicate approval of this Quality Assurance Project Plan (QAPP) and commitment to following the procedures noted.

/s/ 02/08/2012

Stephen Kraemer, Task Order Manager — Date
U.S. EPA ORD

/s/ 02/08/2012

John M. Johnston, Chief, Regulatory Support Branch — Date
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Texas A&M University

EPA does not consider this internal planning document an official Agency dissemination of information under the Agency's Information Quality Guidelines, because it is not being used to formulate or support a regulation or guidance; or to represent a final Agency decision or position. This planning document describes the quality assurance/quality control activities and technical requirements that will be used during the research study. EPA plans to publish the research study results in a draft report, which will be reviewed by the EPA Science Advisory Board. The final research report would be considered the official Agency dissemination. Mention of trade names or commercial products in this planning document does not constitute endorsement or recommendation for use.

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A3 Distribution List

An electronic copy of this QAPP will be provided to all staff involved in this project, including:

Stephen Kraemer, U.S. EPA ORD

James Kitchens, U.S. EPA ORD

Thomas Johnson, U.S. EPA ORD

Laura Blake, The Cadmus Group, Inc.

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An electronic copy of this QAPP will also be provided to the following individuals for informational purposes:

David Jewett, U.S. EPA ORD

Steve Vandegrift, U.S. EPA ORD

Jim Weaver, U.S. EPA ORD

John Johnston, U.S. EPA ORD

A4 Project/Task Organization

Project organization is depicted in Figure 1.

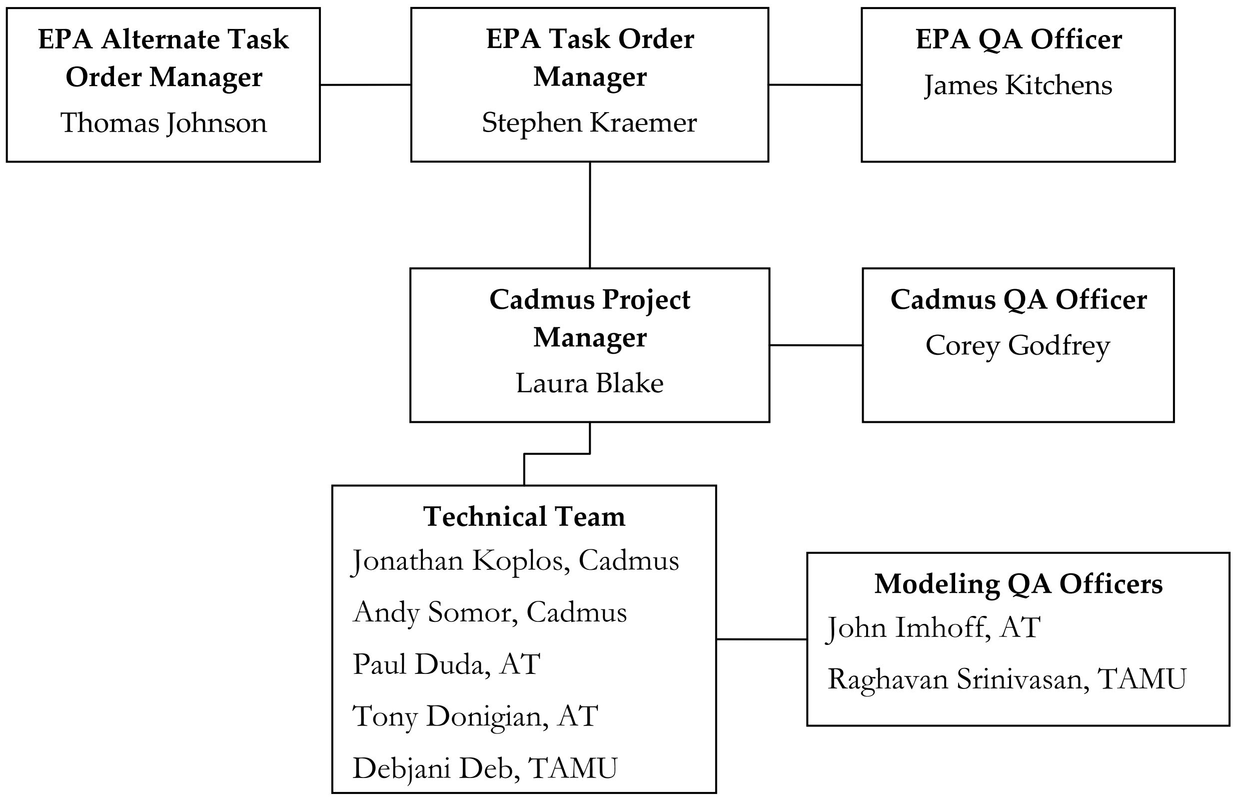

Figure 1. Project organization chart.

Stephen Kraemer is responsible for: overall project oversight, providing technical direction, review and approval of all draft and final deliverables (including the QAPP), management of project records, quality assurance review, and resolution of quality assurance issues.

Thomas Johnson will assume responsibility for Stephen Kraemer's duties if Stephen Kraemer is not able to perform his duties.

James Kitchens is responsible for: review and approval of the QAPP, conducting audits, and review of the draft and final deliverables for quality assurance.

Laura Blake is responsible for: management of the work performed by Cadmus and Cadmus' subcontractors (including providing technical direction), ensuring progress is commensurate with project scope, budget, and schedule, day-to-day communication with project staff and EPA (including serving as primary point of contact for EPA), review and approval of all draft and final deliverables prior to submittal to EPA, and ensuring implementation of the approved QAPP.

Corey Godfrey is responsible for contributing to the preparation of the QAPP, reviewing/auditing Cadmus' project activities, and reviewing corrective actions.

Jonathan Koplos and Andy Somor are responsible for data collection, scenario development, completing assigned work on schedule, and adhering to the approved QAPP.

Paul Duda, Tong Zhai, Tony Donigian, and Debjani Deb are responsible for calibration, validation, and application of the HSPF and SWAT models, development of journal articles, completing assigned work on schedule, and adhering to the approved QAPP.

John Imhoff and Raghavan Srinivasan are responsible for contributing to the preparation of the QAPP, reviewing/auditing modeling activities, and reviewing corrective actions.

A5 Problem Definition and Background

Hydraulic fracturing is a well stimulation process used to maximize the extraction of underground resources – oil, natural gas, and geothermal energy. Hydraulic fracturing involves the pressurized injection of fluids commonly made up of water and chemical additives into a geologic formation. The pressure exceeds the rock strength and the fluid opens or enlarges fractures in the rock. As the formation is fractured, a propping agent, such as sand or ceramic beads, is pumped into the fractures to keep them from closing as the pumping pressure is released. The fracturing fluids (water and chemical additives) are then returned to the surface. After the hydraulic fracturing event is completed, some portion of the injected fracturing fluids (depending on site-specific geologic conditions) is pumped through the well from the subsurface along with the natural gas that flows from pores and the induced fractures. Wells used for hydraulic fracturing are drilled vertically, vertically and horizontally, or directionally. Wells may extend to depths greater than 8,000 feet and horizontal sections of a well (laterals) may extend several thousand of feet away from the production pad on the surface.

Advances in technology, along with economic and energy policy developments, have spurred a dramatic growth in the use of hydraulic fracturing across a wide range of geographic regions and geologic formations in the US for both oil and gas production. As the use of hydraulic fracturing has increased, so have concerns about its potential impact on human health and the environment, especially with regard to possible effects on drinking water resources. These concerns have intensified as hydraulic fracturing has spread from the southern and western regions of the US to other settings, such as the Marcellus Shale, which extends from the southern tier of New York through parts of Pennsylvania, West Virginia, eastern Ohio, and western Maryland. In response to public concern, Congress directed the United States Environmental Protection Agency (EPA) to conduct research to examine the relationship between hydraulic fracturing and drinking water resources (USEPA, 2011a).

The goal of this project is to evaluate the potential impacts of large volume water withdrawals associated with hydraulic fracturing activities from ground and surface waters on the hydrologic cycle in the Susquehanna River Basin (Figure 2) and Upper Colorado River Basin (Figure 3), focusing specifically on stream flow (i.e., magnitude, variability, extreme statistics) and groundwater recharge. This goal will be met through six sub-objectives:

1. ***Baseline - Susquehanna.*** Use the Hydrological Simulation Program FORTRAN (HSPF) model to simulate hydrologic conditions in the Susquehanna River basin prior to commencement of hydraulic fracturing activities, focusing specifically on stream flow (i.e., magnitude, variability, extreme statistics) and groundwater recharge, for the year 2000.

2. ***Baseline - Garfield County***. Use the Soil and Water Assessment Tool (SWAT) to simulate hydrologic conditions in the Upper Colorado River Basin (Garfield County) prior to commencement of hydraulic fracturing activities, focusing specifically on stream flow (i.e., magnitude, variability, extreme statistics) and groundwater recharge, for the year 2000.

3. ***Current - Susquehanna***. Use the HSPF model to evaluate the impacts of large volume water withdrawals associated with hydraulic fracturing activities in the Susquehanna River basin from ground and surface waters on the hydrologic cycle, focusing specifically on stream flow (i.e., magnitude, variability, extreme statistics) and groundwater recharge, for the year 2010.

4. ***Current - Garfield County***. Use SWAT to evaluate the impacts of large volume water withdrawals associated with hydraulic fracturing activities in the Upper Colorado River Basin (Garfield County) from ground and surface waters on the hydrologic cycle, focusing specifically on stream flow (i.e., magnitude, variability, extreme statistics) and groundwater recharge, for the year 2010.

5. ***Futures - Susquehanna***. Use the HSPF model to evaluate the impacts of large volume water withdrawals associated with hydraulic fracturing activities in the Susquehanna River basin from ground and surface waters on the hydrologic cycle, focusing specifically on stream flow (i.e., magnitude, variability, extreme statistics) and groundwater recharge, for each of three 'future' water acquisition scenarios (i.e., business-as-usual, energy max, and green technology) for the predicted peak gas production time period.

6. ***Futures - Garfield County***. Use SWAT to evaluate the impacts of large volume water withdrawals associated with hydraulic fracturing activities in the Upper Colorado River Basin (Garfield County) from ground and surface waters on the hydrologic cycle, focusing specifically on stream flow (i.e., magnitude, variability, extreme statistics) and groundwater recharge, for each of three 'future' water acquisition scenarios (i.e., business-as-usual, energy max, and green technology) for the predicted peak gas production time period.

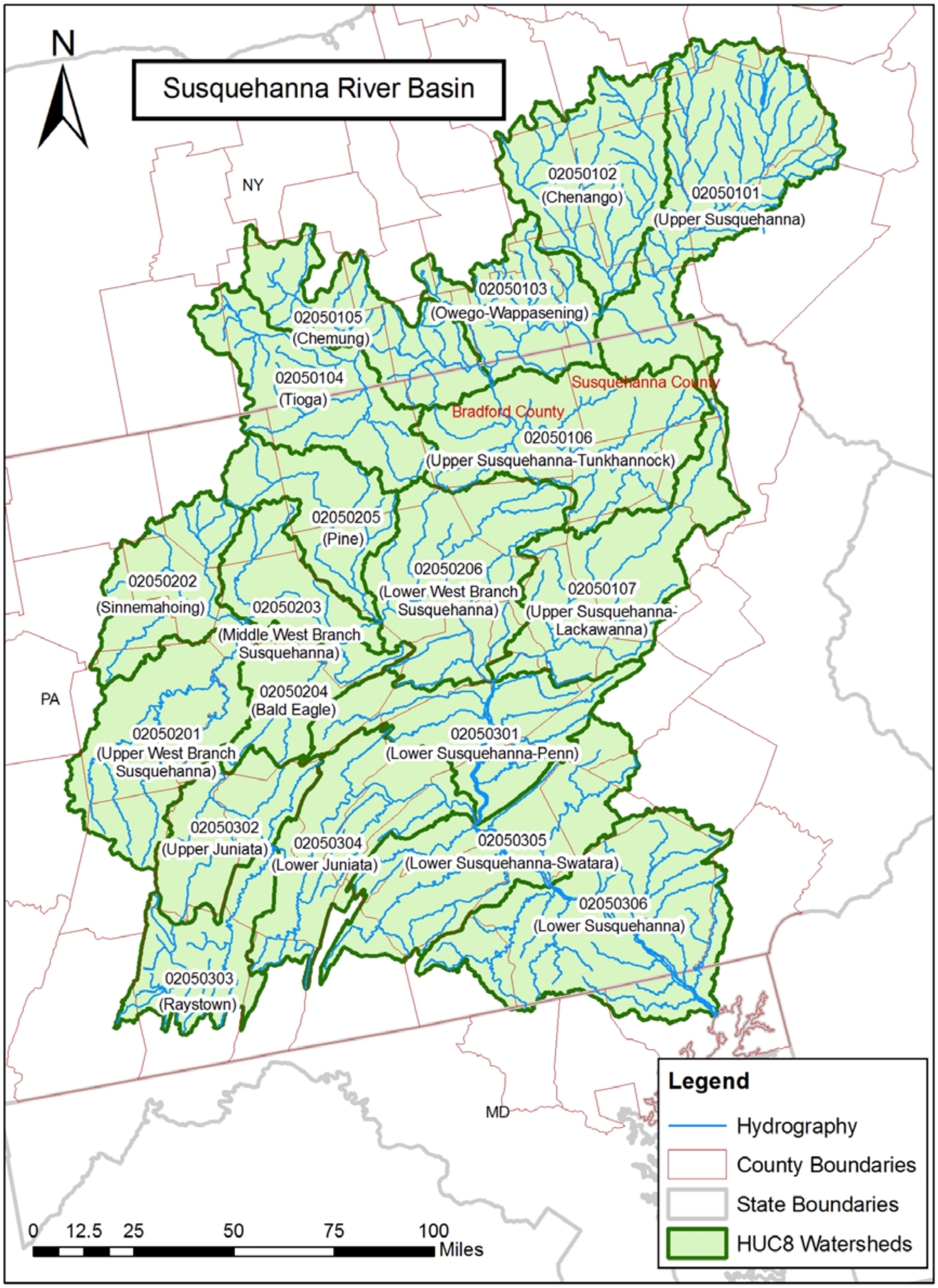

Figure 2. Susquehanna River Basin. Natural gas production is most significant in Susquehanna and Bradford Counties (shown on the map).

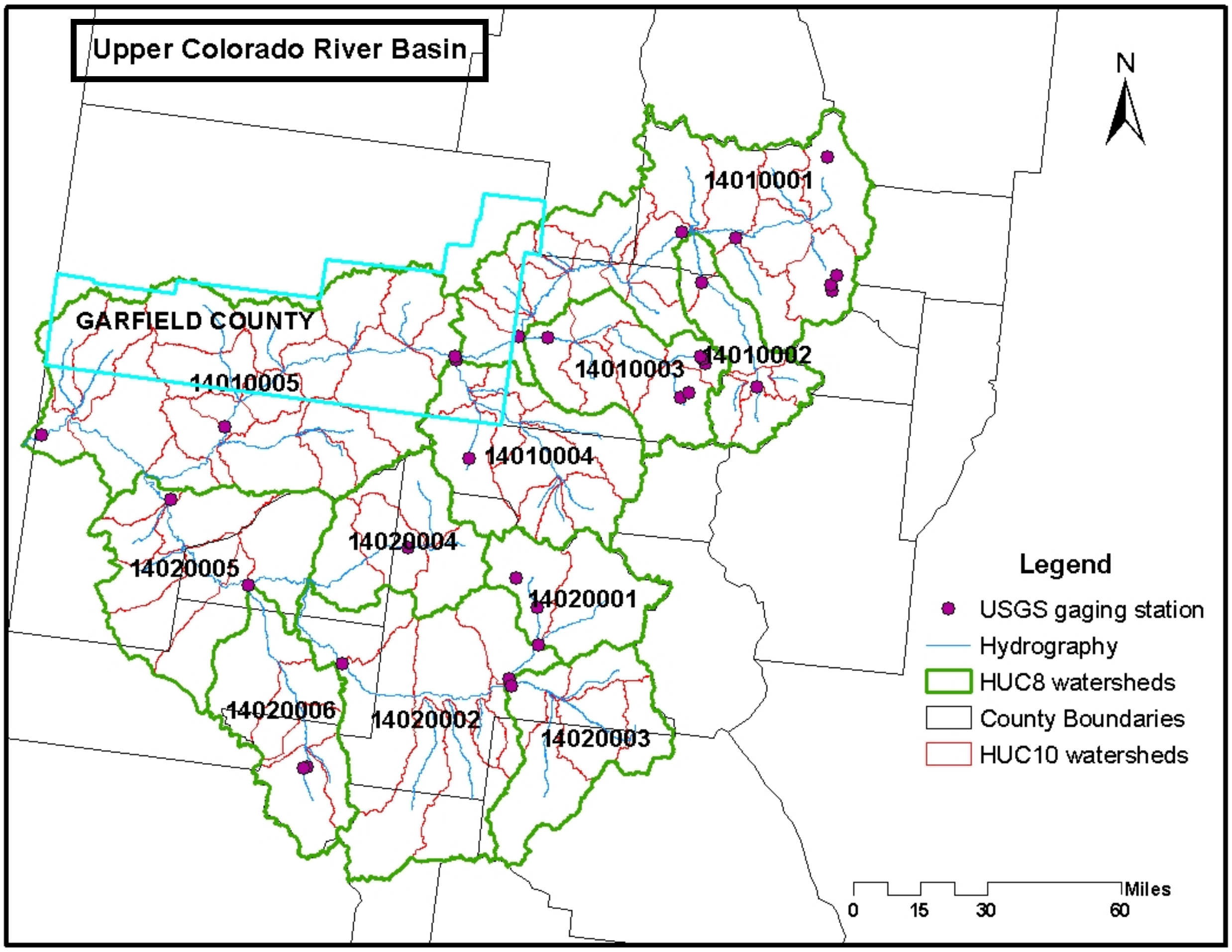

Figure 3. Upper Colorado River Basin.

A6 Project/Task Description

This QAPP will address data analysis and modeling activities as described below.

Hydraulic Fracturing Futures Scenarios for Susquehanna and Upper Colorado River Basins (Task 2)

This effort is defined in response to Task 2 of EPA's Performance Work Statement (PWS).

Three hydraulic fracturing (HF) futures scenarios (*business-as-usual, energy max, and green technology*) will be developed for a time period that is predicted to reflect peak gas production to answer the question "how might different water volume withdrawals from ground and surface water for HF operations alter drinking water availability?" The typical HF well requires between 1 and 5 million gallons of water (quantities are site-specific and influenced by the hydrogeology of the reservoir being developed). While current studies suggest that HF water use represents only a small fraction of total water consumption in most regions, in some localities and some periods (e.g., dry seasons or drought) there can be justified concerns at the sub-basin level about HF consumptive water use (e.g., many of the HF wells needed to exploit the Marcellus shale in the Susquehanna River basin are and will continue to be located in headwater reaches of the basin).

The HF futures scenarios consider the temporal and spatial dynamics of four key factors affecting drinking water availability relevant to this project: growth in the number of HF wells; HF water Best Management Practices (BMPs); competing drinking water demand; and environmental flow management. Scenario output will depict representative annual HF water, drinking water, and environmental flow demands for the predicted peak gas production time period for use as watershed model input. All other major water uses (e.g., power plant cooling water) will remain at the same levels that will be used in the 'current' (2010) scenario (see below). Changes in land use will be included, as these are tightly associated with the population changes that drive drinking water demand.

Below is a description of each scenario and methodology for developing scenario datasets.

Business-as-Usual Scenario

HF well deployment: Under the business-as-usual scenario, standard projections of future HF well deployment in the Susquehanna and Upper Colorado River regions will be obtained for the predicted peak gas production time period. This scenario will utilize current HF well inventory and future deployment schedules from U.S. Energy Information Administration publications, data from the Independent Petroleum Association of America, and modeling results presented in the July 2011 Regulatory Impact Analysis of hazardous pollutants for the oil and natural gas industry by the Office of Air and Radiation. These regional data will be used to inform state-level projections of the number of new HF wells constructed annually for the predicted peak gas production time period. State-level projections will be distributed among watershed model segments (i.e., HUC8 and HUC10 watersheds) using a spatial allocation methodology that estimates the likelihood of future well pad installation at locations within the study areas. The number of wells per pad will be estimated based on the current average and an escalation factor that will be estimated from recent data. Spatial data related to the following variables will be obtained and used to determine the optimal group of predictors for projecting the location of future well deployments:

- Thermal maturity of shale gas reservoirs
- Depth to productive formations
- Thickness of productive formations
- Land surface slope
- Current HF well locations
- Distance to natural gas pipelines
- Distance to roads
- Land use
- Access to water
- Access to disposal
- Zoning

HF water BMPs**:** Under the business-as-usual scenario, current HF water acquisition and disposal practices are maintained during the predicted peak gas production time period. Current practices will be evaluated from existing data on HF water acquisition, production, and disposal, including water source type and location, acquired volume, flowback/produced volume, recycled volume, disposal volume, disposal method, disposal location, and disposal timing relative to acquisition. For the Susquehanna River Basin, information will be obtained from post-hydrofracture water summary reports compiled by the SRBC. Sources of information for HF water use in the Upper Colorado River Basin are currently being explored (e.g., Colorado Oil & Gas Conservation Commission, Colorado Division of Water Resources, etc.). This information will be used in conjunction with HF well deployment projections to create representative annual estimates (for the predicted peak gas production time period) of HF water acquisition and disposal in each watershed model segment. HF water projections will specify the source of acquired water (groundwater vs. surface water), volume acquired, volume recycled, disposal method and volume, and the timing of water acquisition and disposal.

Drinking water demand**:** Under the business-as-usual scenario, increased drinking water demand during the predicted peak gas production time period occurs as a result of steady population growth. EPA's Integrated Climate and Land Use Scenarios (ICLUS) data will be used to estimate the future population of each watershed model segment and drinking water demand (USEPA, 2010). ICLUS population projections are consistent with Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) social, economic, and demographic storylines (Nakicenovic and Swart 2000). For the HF water business-as-usual scenario, population projections will be based on ICLUS scenario B2, which assumes continuously increasing global population under intermediate levels of economic development and strong social development. ICLUS population projections for the 2030 decade are available at the county level and will be spatially distributed among watershed model segments using ICLUS gridded housing density projections. Current, per capita water use rates will be applied to these population projections to estimate the total amount of drinking water demand from surface and ground water sources for the predicted peak gas production time period.

Environmental flow management**:** Under the business-as-usual scenario, water withdrawals are constrained by minimum flow criteria for streams and rivers. Minimum flow criteria (e.g., 10% of $Q_{7\text{-}10}$) will be quantified for watershed model reaches using existing information from published literature and water management agencies.

Energy Max Scenario

HF well deployment**:** The energy max scenario is characterized by full build-out of natural gas reserves in the Susquehanna and Upper Colorado River Basins. High-end estimates of the number of HF wells constructed annually during the predicted peak gas production time period will be developed from information on the size of recoverable natural gas resources in the study areas compiled by the USGS, and the average production efficiency of HF wells. Basin level estimates of the number of HF wells will be spatially distributed among watershed model segments (i.e., HUC8 and HUC10 watersheds) using the well pad spatial allocation methodology described above. Rather than use the current average number of wells per pad however, the energy max scenario will assume full build-out of well pads (more wells per acre) before increasing the number of wells per pad. Current constraints on well pad density (e.g., 40-160 acres per well in Pennsylvania) will be applied.

HF water BMPs: Current HF water management practices will be assumed to continue throughout the energy max scenario. Water acquisition, recycling, and disposal projections developed for the business-as-usual scenario will be adjusted to account for the increased number of HF wells under the energy max scenario.

Drinking water demand: Under the energy max scenario, high-end estimates of population growth in the study areas will be realized and will drive a high demand for drinking water. Population projections for the 2030 decade will be based on ICLUS scenario A2, which describes a world with regionalized economic growth, a focus on family and community, and high fertility. Current, per capita water use rates will be applied to these population projections to estimate the total amount of drinking water demand from surface and ground water sources for the predicted peak gas production time period.

Environmental flow management: No constraints on water withdrawals will be implemented for the energy max scenario.

Green Technology Scenario

HF well deployment: Under the green technology scenario, HF well expansion will keep pace with current trends. HF well projections for the scenario will be similar to those developed for the business-as-usual scenario. However, the number of wells per pad will be maximized, resulting in fewer pads overall. Increased number of wells per pad is widely considered to reduce environmental impact and results in trade-offs between increased pressure on local water resources and increased potential for recycling of produced water.

HF water BMPs: The green technology scenario is characterized by the use of advanced technology to maximize flowback and produced water recycling for future HF water use. Current data on flowback/produced water volumes from the post-hydrofracture water summary reports will be used to inform projections of HF water acquisition, recycling, and disposal for each watershed model segment. An increase in the amount of produced water that is recycled for subsequent HF well fracturing will be assumed based on the higher number of wells per pad.

Drinking water demand: Under the green technology scenario, drinking water demand will be minimized as a result of low population growth in the study areas. Population projections for the 2030 decade will be based on ICLUS scenario B1, which reflects a world undergoing rapid economic and social development with a sustainable focus and low population growth. Current, per capita water use rates will be applied to these population projections to estimate the total amount of drinking water demand from surface and ground water sources for the predicted peak gas production time period.

Environmental flow management: Under the green technology scenario, water withdrawals are regulated under a suite of environmental flow criteria. Flow criteria will be quantified for watershed model reaches using information from published literature and water management agencies. For example, the *Ecosystem Flow Recommendations for the Susquehanna River Basin* report (The Nature Conservancy, 2010) outlines several ecological flow recommendations for the Susquehanna River basin.

Baseline Scenario - Susquehanna River Basin HSPF Model (Task 3)

This effort is defined in response to Task 3 of EPA's PWS. It entails performance of six sub-tasks. Requirements that are defined in the PWS are indicated in quotation marks.

Sub-task 3.1

"The contractor shall acquire the baseline calibrated and tested/validated HSPF model of the Susquehanna River basin for the period 1970-2000, from the Watershed Study. The performance shall be evaluated based on annual water balance and county level resolution."

The baseline Susquehanna River Basin simulation for the 20 Watersheds Study was performed for the period 1985-2005. The model featured a level of detail comparable to HUC10s, resulting in 278 sub-basins. The basin is comprised of 19 HUC8s (Figure 2).

A water balance equation for the 'baseline' condition will be developed and used to express relative magnitudes of the hydrological processes and water use practices that define the Susquehanna River Basin water supply. The components of the water balance equation will include precipitation, evapotranspiration, loss to deep groundwater and streamflow. The streamflow component will be further refined to provide information on specific withdrawal and/or return flow categories (e.g., HF, public drinking water, thermoelectric cooling, industrial, other mining, irrigation, etc.). Significant groundwater withdrawals for public water supply or other uses will be included in the model water balance equations for both the 'baseline' and 'current' condition scenarios. The 'baseline' condition equation has no need for a component that represents HF water use, since there was none. A second water balance equation will be developed for the 'current' condition that adds a component representing HF water use to the 'baseline' condition equation.

At the pour points for the 19 HUC8s, the values for the hydrological components of the water balance equations for both the 'baseline' and 'current' condition scenarios will be determined (for average annual conditions and including the appropriate annual water use data), thus providing a comparable level of resolution to "county level." Additional water balance summaries for sample years that are representative of "wetness" classifications (e.g., a drought year) could also be developed as needed.

Sub-task 3.2

"The performance of the model shall be compared to the performance of the Chesapeake Bay Phase *5.3* Watershed Model. The contractor shall make adjustments to the calibration if warranted. The contractor shall segregate the simulation years into drought, dry, median, wet, and very wet conditions, and label the condition to each year. The contractor shall provide EPA with the data and model input files."

The primary means of comparing the performance of the two models will be statistical and graphical comparison of the daily streamflow values for 1985-2005 that the two models simulate at the three calibration sites for the 20 Watersheds Study Susquehanna Model: (1) the USGS gage on the Raystown Branch of the Juniata River at Saxton, PA (USGS 02050303); the gage on the Susquehanna River at Danville, PA (USGS 01540500); and the gage on the Susquehanna River at

Marietta, PA (USGS 01576000). These three sites were selected to calibrate the 20 Watersheds Susquehanna model because they offered long-term, high quality flow gaging and water quality data that accommodated both hydrology and water quality calibration. The first of these (Raystown Branch Juniata River) was selected for initial calibration, with subsequent adjustments based on comparison to data at two stations on the mainstem Susquehanna.

Another useful comparison will be annual simulated results for streamflow and groundwater recharge for the 19 HUC8s. This comparison offers an indicator that the project Susquehanna model estimates values for water balance components that are comparable to those estimated by the more detailed CBP Phase 5.3 model. If comparison of the two models suggests a rationale and need, a fine-tuning of the calibration for the 20 Watersheds model will be performed and documented.

Classification of the simulation years into drought, dry, median, wet and very wet conditions will be derived from a flow-duration curve developed for the observed annual streamflow values at the Marietta, PA gage. The 25th and 75th percentile flow values will be used to as the upper cut-off for wet and dry years, respectively. Either the 10% or 5% (or 90% or 95%) values will be used as the cut-off for very wet and drought years. This decision will be made jointly with the EPA Task Order Manager (TOM) after reviewing the flow-duration curve.

Sub-task 3.3

"The contractor shall resolve the HSPF model representation for the year 2000 by including the major reservoirs, and representing the major water uses by county (surface water, groundwater, municipal water supply, treated wastewater from municipal and industrial treatment facilities, power plant cooling water, and recycled produced water) as documented by the US Geological Survey (USGS) (Hutson et al., 2004, USGS Circular 1268). The calibration and testing of the HSPF model shall be checked and renewed if necessary. The contractor shall provide EPA with the data and model input files."

While there are many dams in the study area, their influence was not explicitly included in the 20 Watersheds Study. The largest of the reservoirs are on the Susquehanna River near the outlet of the study area, well below the model's endpoint at the USGS gage on the Susquehanna River at Marietta. For the 20 Watersheds Study model the impacts of these reservoirs were assumed to be implicitly represented through the tabular representation of reach hydrologic response (FTables). We will request from EPA CBPO any reservoir representations that are included in the Phase 5.3 Model and evaluate their potential to improve streamflow (and water availability) simulation if integrated into the model that will be used for the HF project. Justifiable enhancements will be implemented.

There are numerous point source discharges in the watershed. For the purposes of the 20 Watersheds Study modeling, only the 147 major dischargers with a design flow greater than 1 MGD were included in the simulation. The major dischargers account for the majority of the facilities, so the effect of the omitted sources distributed throughout the watershed will be relatively small, except during extreme low flow conditions. In the event that model results are used to evaluate headwater sub-basins where additional point sources may play a significant role in water availability, we will re-visit the point source database and consider representation of additional discharges of lesser magnitude.

County-based water use data will be used as the starting point for integration into the HF Susquehanna model. As deemed necessary, an appropriate method will be identified and implemented to distribute Year 2000 water use among the smaller sub-basins contained within the HUC8s. Significant water uses achieved by means of groundwater withdrawals will be introduced into the model as external sources, and depending on the type of use, the need and potential for representing return flows will be considered. The source of significant surface water withdrawals (which comprise 93% of the total Year 2000 water use) will be determined at an appropriate spatial scale to support the model, and these will be modeled as diversions. The diversions will be 'mapped' against the point sources represented in the model, and the need for representing additional point source or nonpoint source return flows will be considered and implemented if warranted. Particular attention will be paid to representing public water supply surface water intakes and water supply wells with sufficient spatial resolution to meet study objectives. This information will be integrated into the model using a level of spatial detail that parallels that used to represent the HF operations. (Note that the 20 Watersheds Study concluded that "A variety of water withdrawals occur in the Susquehanna, but these have a relatively small effect on the overall water balance.") The impacts on calibration of integrating the reservoir improvements and the water uses will be evaluated. A fine-tuning of the calibration will be performed and documented if necessary.

Sub-task 3.4

"The contractor shall further resolve the HSPF model representation for the year 2000 by county by inclusion of HF and associated water operations. This period preceded the boom in unconventional shale gas production (horizontal well drilling and slick water fracturing). The EPA will provide the water data supplied by the Susquehanna River Basin Commission. The calibration and testing of the HSPF model shall be checked and renewed if necessary. The contractor shall provide EPA with the data and model input files."

Subsequent investigation has determined that HF operations in the Susquehanna Basin began with a pilot operation in 2005. Since the stated objective (see Section A5) of this task is to evaluate the impacts of large volume water withdrawals associated with hydraulic fracturing activities, it was determined that such an evaluation would necessitate simulation of an alternative condition that represented a point in time when HF operations had grown significantly. The Year 2010 condition has been selected for this purpose and will be called the 'current' condition scenario. The 'current' condition scenario will inherit all enhancements made to the 'baseline' model, but will superimpose HF water use data that represents operations in 2010. In addition, the 2000 USGS water use data represented in the 'baseline' model will be replaced with the most current water use data that are available from the USGS (Kenny et al., 2009, USGS Circular 1344).

Sub-task 3.5

"The contractor shall perform an impact assessment on drinking water resources (surface and subsurface) of HF water use for the year 2000. The year 2000 will be classified as to whether within drought, dry, median, wet, or very wet flow period. The impact assessment shall evaluate the magnitude of any changes to the hydrological cycle, specific to HF water acquisition, including stream flow (magnitude, variability, and extremes statistics) and groundwater recharge."

The 'current' conditions scenario will be simulated, and the results for the calibration period will be statistically and graphically evaluated to determine whether there is an apparent need for model re-calibration – if so, the re-calibration will be performed and documented.

The 'baseline' and the 'current' condition scenarios will be compared, and impacts of HF operations will be identified and described. The method used for developing water balance summaries for the 'baseline' scenario will be repeated for the 'current' conditions scenario, but a HF component will be added to the summaries. We will evaluate and document the magnitude of any changes to the hydrological cycle, specific to HF water acquisition, including stream flow (magnitude, variability, and extremes statistics) and groundwater recharge."

Sub-task 3.6

A "ready for submittal" journal manuscript documenting the impact assessment will be submitted to EPA.

Baseline Scenario - Upper Colorado River Basin (Garfield County) Model (Task 4)

This effort is defined in response to Task 4 of the PWS. It entails performance of five sub-tasks. Requirements that are defined in the PWS are indicated in quotation marks.

Sub-task 4.1

"The contractor shall acquire the baseline calibrated and tested/validated SWAT model of the Upper Colorado River basin for the period 1970-2000, from the Watershed Study. The performance shall be evaluated based on annual water balance and county level resolution. The performance of the model shall be compared to the performance of Variable Infiltration Capacity (VIC) model as part of the Bureau of Reclamation's Colorado River Basin Water Supply and Demand Study, assuming the annual water balance data for relevant counties is available to EPA. The contractor shall make adjustments to the calibration if warranted. The contractor shall segregate the simulation period into annual drought, dry, median, wet, and very wet conditions, and label the condition to each year."

The baseline simulation for the Upper Colorado River basin was performed for the period 1982-2002 as part of the 20 watershed study. This basin consists of 89 sub-basins at the HUC10 watershed scale (Figure 3). As part of this study, the performance of the already calibrated and validated model will be evaluated based on water balance that will include hydrologic components such as precipitation, evapotranspiration, streamflow and losses to deep groundwater. This will help in defining the relative magnitudes of the hydrological processes and water use practices that characterize the water supply in the Upper Colorado River basin. The water balance at various locations from the Upper Colorado basin SWAT model will be compared to the water balance at the county level provided by EPA.

In addition, the SWAT model performance will be compared to the outputs from the VIC model. The primary means of comparing the performance of the two models will be statistical and graphical comparison of the daily streamflow values for 1982-2002 that the two models simulate at the various calibration sites over the watershed. Another useful comparison will be annual average values for the different hydrologic components at the basin scale. If comparison of the two models suggests a rationale and need, a fine-tuning of the calibration for the 20 Watersheds model will be performed and documented.

Also, water balance summaries for sample years that are representative of "wetness" classifications (e.g., drought, dry, median, wet, and very wet year) will be developed as needed. Classification of the simulation years into drought, dry, median, wet and very wet conditions will be derived from flow-duration curves. The 25th and 75th percentile flow values will be used to as the upper cut-off for wet and dry years, respectively. Either the 10% or 5% (or 90% or 95%) values will be used as the cut-off for very wet and drought years. This decision will be made jointly with the EPA after reviewing the flow-duration curves.

Sub-task 4.2

"The contractor shall resolve the SWAT model representation for the year 2000 by including the major water uses by county (surface water, groundwater, municipal water supply, treated wastewater from municipal and industrial treatment facilities, power plan cooling water, and recycled produced water) as documented by the USGS (Hutson et al., 2004, USGS Circular 1268). The calibration and testing of the SWAT model shall be checked and renewed if necessary."

The SWAT simulation for the Upper Colorado River in the 20 Watersheds Study basin did not utilize the water use components and therefore the 'baseline' SWAT model will be modified by incorporating major water uses by county for the year 2000 (surface water, groundwater, municipal water supply, treated wastewater from municipal and industrial treatment facilities, power plan cooling water, and recycled produced water) as documented by the USGS (Hutson et al., 2004, USGS Circular 1268). The streamflow component will be further refined to provide information on specific withdrawal and/or return flow categories (e.g., HF, public drinking water, thermoelectric cooling, industrial, other mining, irrigation, etc.). Significant groundwater withdrawals for public water supply or other uses will be included in the model water balance equations for both the 'baseline' and 'current' condition scenarios. The values for the hydrological components of the water balance equations for both the 'baseline' and 'future' condition scenarios will be compared (for average annual conditions and including the appropriate annual water use data) and calibration will be refined and documented if necessary.

Sub-task 4.3

"The contractor shall further resolve the SWAT model representation for the year 2000 for Garfield County by sub-basin by the inclusion of HF water operations. EPA will provide the water data supplied by the Colorado Oil and Gas Commission. The calibration and testing of the SWAT model shall be checked and renewed if necessary."

Since the objective of this task is to evaluate the impacts of large volume of water withdrawals associated with hydraulic fracturing activities, it was determined that such an evaluation would necessitate simulation of an alternative condition that represented a point in time when HF operations had grown significantly. The year 2010 condition has been selected for this purpose and will be called the 'current' condition scenario. The 'current' condition scenario will inherit all enhancements made to the 'baseline' model, but will superimpose HF water use data that represents operations in 2010. The 2000 USGS water use data represented in the 'baseline' model will be replaced with the most current water use data that are available from the USGS (Kenny et al., 2009, USGS Circular 1344). A separate SWAT model for the region in Garfield County may be set up if necessary. The 'current' conditions scenario will be simulated, and the results for the calibration period will be statistically and graphically evaluated to determine whether there is an apparent need for model re-calibration – if so, the re-calibration will be performed and documented.

Sub-task 4.4

"The contractor shall perform an impact assessment on drinking water resources (surface and subsurface) of HF water use for the year 2000. The year 2000 will be classified as to whether within drought, dry, median, wet, or very wet flow period. The impact assessment shall evaluate the magnitude of any changes to the hydrological cycle, specific to HF water acquisition, including stream flow (magnitude, variability, and extremes statistics) and groundwater recharge."

The 'baseline' and the 'current' condition scenarios will be compared, and impacts of HF operations will be identified and described. The method used for developing water balance summaries for the 'baseline' scenario will be repeated for the 'current' conditions scenario, but a HF component will be added to the summaries. Classification of the year 2000 into drought, dry, median, wet and very wet conditions will be derived from flow-duration curves for that year. We will evaluate and document the magnitude of any changes to the hydrological cycle, specific to HF water acquisition, including stream flow (magnitude, variability, and extremes statistics) and groundwater recharge and will write a journal manuscript ready for submittal documenting the impact assessment.

Sub-task 4.5

A "ready for submittal" journal manuscript documenting the impact assessment will be submitted to EPA.

Futures Scenario - Susquehanna River Basin HSPF Model (Task 5)

This effort is defined in response to Task 5 of the PWS. Requirements that are defined in the PWS are indicated in quotation marks.

"The contractor shall implement the HF futures for water acquisition for the Susquehanna River basin into the HSPF model, for the years 2020-2040, including the business-as-usual, the energy max, and the green technology scenarios. The meteorological forcing on the model will include the year 2000 observed data, and will also include representative forcing informed by drought, low flow, median flow conditions based on the Watershed Model 1970-2000 and 2040-2070 simulations. The contractor shall document results of the drinking water resource impact in a journal manuscript ready for submittal, including investigations of stream flow (magnitude, variability, extremes statistics, and potentially ecological flows) and groundwater recharge mapping."

Each of the three Susquehanna River Basin 'future' scenarios that result from the Task 2 effort will be implemented using the 'current' conditions scenario as a starting point. The 'future' scenarios will dictate changes in land use, water use, and instream flow criteria. EPA will provide precipitation and air temperature "delta" data appropriate to modify the observed 1985–2005 observed hourly values to represent projected weather conditions for the predicted peak gas production time period, consistent with IPCC SRES scenarios B2, A2, and B1. EPA ORD's Climate Assessment Tool

(CAT) (USEPA, 2009) will be used to combine the modified weather data with each of the HSPF model 'future' scenarios to perform the required simulations and analyses.

The three 'future' scenarios will be compared to the 'baseline' condition to provide useful information on relative impact. However, the preliminary research design that EPA has requested will not provide full clarity in evaluating the impact of HF alone on drinking water, since confounding variables will be present in the 'future' scenarios (e.g., changes in population, climate, land use, drinking water demand). Simulating an additional *no HF* 'future' scenario would remove many or most of the confounding variables and may solve this problem. A decision of whether or not to add the *no HF* 'future' scenario to the research design will be made jointly by EPA and the Cadmus Team after further consideration.

A "ready for submittal" journal manuscript documenting the impact assessment will be submitted to EPA.

Futures Scenario - Upper Colorado River Basin (Garfield County) Model (Task 6)

This effort is defined in response to Task 6 of the PWS. Requirements that are defined in the PWS are indicated in quotation marks.

"The contractor shall implement the HF futures for water acquisition for the Garfield County watershed model, for the years 2020-2040, including the business-as usual, the energy max, and the green technology scenarios. The meteorological forcing on the model will include the year 2000 observed data, and will also include representative forcing informed by drought, low flow, median flow conditions based on the Watershed Model 1982–2002 and 2040-2070 simulations. The contractor shall document results of the drinking water resource impact in a journal manuscript ready for submittal, including investigations of stream flow (magnitude, variability, extremes statistics, and potentially ecological flows) and groundwater recharge mapping."

Each of the three Upper Colorado River Basin 'future' scenarios that result from the Task 2 effort will be implemented using the 'current' conditions scenario as a starting point. The 'future' scenarios will dictate changes in land use, water use, and instream flow criteria. EPA will provide precipitation and air temperature "delta" data appropriate to modify the observed 1982–2002 observed daily values to represent projected weather conditions for the predicted peak gas production time period, consistent with IPCC SRES scenarios B2, A2, and B1. EPA ORD's Climate Assessment Tool (CAT) (USEPA, 2009) will be used to combine the modified weather data with each of the SWAT model 'future' scenarios to perform the required simulations and analyses.

The three 'future' scenarios will be compared to the 'baseline' condition to provide useful information on relative impact. However, the preliminary research design that EPA has requested will not provide full clarity in evaluating the impact of HF alone on drinking water, since confounding variables will be present in the 'future' scenarios (e.g., changes in population, climate, land use, drinking water demand). Simulating an additional *no HF* 'future' scenario would remove many or most of the confounding variables and may solve this problem. A decision of whether or not to add the *no HF* 'future' scenario to the research design will be made jointly by EPA and the Cadmus Team after further consideration.

A "ready for submittal" journal manuscript documenting the impact assessment will be submitted to EPA.

Project Task Schedule

The schedule for completing the project is shown in Table 1. Cadmus' monthly technical progress reports to be submitted by the 20th of each month.

Table 1. Project schedule.

Task order award	November 23, 2011
Project scoping conference call	December 5, 2011
Project team call	January 9, 2012
Draft QAPP including HF futures scenario approach (Task 1)	January 23, 2012
EPA preliminary comments on draft QAPP (Task 1)	January 26, , 2012
EPA additional comments on draft QAPP (Task 1)	January 31, , 2012
Final QAPP (Task 1)	February 3, , 2012
EPA approval of QAPP (Task 1)	February 6, 2012
Project team call	February 3, 2012
Project team call	March 2, 2012
Baseline Scenario – Susquehanna HSPF Manuscript (Task 3)	March 30, 2012
Baseline Scenario – Upper Colorado SWAT Manuscript (Task 4)	March 30, 2012
Project team call	April 6, 2012
HF Futures Scenarios (Task 2)	April 30, 3012
Project team call	May 4, 2012
Project team call	June 1, 2012
Preliminary model results - Futures Scenario – Susquehanna HSPF	June 30, 2012
Preliminary model results - Futures Scenario – Upper Colorado SWAT	June 30, 2012
Project team call	July 6, 2012
Project team call	August 3, 2012
Project team call	September 7, 2012
Futures Scenario – Susquehanna HSPF Manuscript (Task 5)	September 30, 2012
Futures Scenario – Upper Colorado SWAT Manuscript (Task 6)	September 30, 2012
Project team call	October 5, 2012
Project team call	November 2, 2012
Project team call	December 7, 2012
Deliver models, data, and other project files to EPA	December 14, 2012
Task order end date	December 31, 2012

A7 Data Quality Objectives and Criteria

This project does not include primary data collection. Secondary data (i.e., non-direct measurements) of known and documented quality and provided by qualified sources (e.g., published journal papers, agency reports, etc.) will be used for all project tasks. All acquired data will be collected as electronic data files. Data will be reviewed for errors or inconsistencies with known condition, and assessed against acceptance criteria (see Section B9). The quality of the data will be judged using information in the source documents, from websites of origin, or directly from the authors. If the quality of the data can be adequately determined, the data will be used. Otherwise, a case-by-case basis determination will be made regarding the use of the data. One possible option for using data lacking documentation of quality is to determine a possible order of magnitude of variation in the data values and present an uncertainty band around the model results. Information on data quality will be documented, along with a summary of any case-by-case determinations made regarding the use of data lacking documentation of quality.

Data Quality Objectives for Model Output

The data quality objectives for the Susquehanna River Basin HSPF Model and the Upper Colorado River Basin SWAT Model are shared. The quality assurance process for this type of study consists of using appropriate data, data analysis procedures, modeling methodology and technology, administrative procedures, and auditing. To a large extent, the quality of the modeling study is determined by the expertise of the modeling and quality assessment teams, in addition to the available data. The ultimate test of quality for this study, however, is that the model output is a sufficiently accurate representation of the natural system to address the study objectives/data quality objectives listed below.

The proposed modeling study design was developed to (1) represent the year 2000 'baseline' condition scenario, the year 2010 'current' conditions scenario, and the 'future' predicted peak gas production time period hydrology and water use in the Susquehanna and Upper Colorado River Basins, and to (2) address each of the following specific study objectives, which also serve as the DQOs for the model output:

- Enhance and simulate existing 'baseline' scenarios for the two basins to include improved representation of reservoirs.
- Enhance and simulate existing 'baseline' models to include representation of Year 2000 surface and groundwater withdrawals that would compete with HF withdrawals, as well as additional return flows that are significant to the water balance within the basins.
- Develop and simulate 'current' conditions scenarios for the two models that include Year 2010 HF withdrawals and return flows and the most current USGS data for competing water use.
- Assess impact of HF water use on drinking water resources for the 'current' condition scenarios (year 2010) for the two models.
- Develop, simulate and evaluate 'future' scenarios (predicted peak gas production time period) for three alternatives: (1) business-as-usual, (2) energy maximum and (3) green technology. Assess potential impacts of HF development alternatives.

Determination of whether the DQOs have been achieved is less straightforward for a modeling study than for the more typical sampling and analysis type of study. The usual data quality indicators (e.g., completeness, accuracy, precision) are difficult to apply and in many cases do not adequately characterize model output. Nonetheless, there are objective techniques that can be used to evaluate the quality of the model performance and output. These methods and the proposed performance expectations are now discussed.

Model Calibration and Validation

Model calibration is the process of adjusting model inputs within acceptable limits until the resulting predictions give good comparison with observed data. Commonly, calibration begins with the best estimates for model input based on measurements and subsequent data analysis. Results from initial simulations are then used to improve the concepts of the system or to modify the values of the model input parameters. The use of calibrated models, the scientific veracity of which is well defined and documented, is of paramount importance to this project. Because the goal is to be able to assess the potential impacts of hydraulic fracturing water use on drinking water supply, model calibration and validation should strive to minimize errors (deviations between model predictions and observed measurement data).

The Susquehanna and Upper Colorado models that will be used as the starting point for the HF study have already been calibrated as a component of the previous "20 Watersheds Study" (Tetra Tech, 2011). However, this study calls for refinement of the models to enable achieving the study objectives. Re-evaluation of the model calibrations that were achieved for the 20 Watersheds Study is called for at two points in the study effort: (1) after comparison of each of the 'baseline' models to an alternative model for the same basin, and (2) after integration of model refinements related to representing reservoirs and water withdrawals that compete with HF withdrawals.

The Cadmus Team Lead Modelers will direct the model calibration efforts to the extent that they are required. The experience and judgment of the modelers are a major factor in calibrating (or re-calibrating) a model accurately and efficiently. Further, the model should meet pre-specified quantitative measures of accuracy to establish its acceptability in answering the principal study questions.

The model calibration process proceeds through both qualitative and quantitative analyses. As is the established approach, qualitative measures of calibration progress will be based on the following:

- Graphical time-series plots of observed and predicted data
- Graphical transect plots of observed and predicted data at a given time interval
- Scatter plots of observed versus predicted values in which the deviation of points from a 45- degree straight line gives a sense of fit
- Tabulation of measured and predicted values and their deviations

Models are considered calibrated when they reproduce data within an acceptable level of accuracy. In the case of re-calibration, the objective will be to achieve equal or better levels of accuracy than those achieved by the previous versions of the 'baseline' models that embodied a coarser level of detail.

A set of parameters used in a calibrated model may not accurately represent field values, and the calibrated parameters may not represent the system under a different set of boundary conditions or hydrologic stresses. A model validation period helps establish greater confidence in the calibration and the predictive capabilities of the model. A site-specific model is considered validated if its accuracy and predictive capability have been proven to be within acceptable limits of error independently of the calibration data. In general, model validation is performed using a data set separate from the calibration data. If only a single time series is available, the series may be split into two subseries, one for calibration and another for validation. If the model parameters are changed during the validation, this exercise becomes a second calibration, and the first calibration needs to be repeated to account for any changes. Representative stations are used to guide parameter adjustment to get an accurate representation of the conditions of the individual sub-watersheds and streams.

The 'baseline' Susquehanna and Upper Colorado models have undergone validation as part of the work performed for the previous 20 Watersheds Study. The two basins were simulated for the period 1985-2005 (HSPF) and 1982-2002 (SWAT). Since land use was based on 2001 NLCD information, the second ten years of the simulation period for each model was selected for calibration, while the earlier ten-year period of simulation was used for validation tests. Because the land use distribution more accurately depicted conditions during the calibration periods, validation results did not achieve the same quantitative acceptance levels as for calibration; however, the majority of the performance metrics were achieved (Tetra Tech, 2001). Re-evaluation of model performance for the calibration period when the reservoir and water use refinements have been integrated is warranted and will be performed.

Model testing includes calibration, verification, and validation. Model calibration and validation were previously described. Model verification is the process of testing the model code, including program debugging, to ensure that the model implementation has been done correctly. Testing usually begins with the best estimates for model input based on measurements and subsequent data analyses. Results from initial simulations are then used to improve the concepts of the system or to modify the values of the model input parameters.

For this project, existing tested model code will be used (HSPF and SWAT). HSPF has been applied to hundreds of watersheds throughout the United States and internationally. The model has gained widespread acceptance by federal agencies States and water districts. HSPF is included as a core watershed model in EPA's BASINS modeling system (http://water.epa.gov/scitech/datait/models/basins/index.cfm) and the USACE's Watershed Management System (http://chl.erdc.usace.army.mil/wms). It is listed as a "Nationally Accepted Hydrologic Model" by FEMA (http://www.fema.gov/plan/prevent/fhm/en_hydro.shtm#2). SWAT model code has been tested and verified as a hydrologic model under different environmental conditions both nationally and internationally as is evidenced by more than 600 peer reviewed publications (Gassman et al., 2007, Gassman et al., 2005). Additional model verification is required only for new "bridge" codes, such as those required to translate 'future' scenarios into model input.

The work proposed for this project differs from other, more common applications of watershed models (e.g., for TMDLs) in several ways that affect the re-calibration strategy:

- Models will be refined for two different watersheds, and calibration will be done by two different teams of modelers. The two teams should apply the same calibration metrics.
- Different models (i.e., HSPF and SWAT) will be used to simulate the scenarios in the Susquehanna and Upper Colorado River Basins. These two models were previously calibrated for the Susquehanna and Upper Colorado River Basins for use in the 20 Watersheds Study (Tetra Tech 2011). This project is leveraging the extensive work conducted for the 20 Watersheds Study.
- A common set of calibration criteria should be applied to both models to facilitate comparison.
- Model application is not for regulatory purposes, but rather to inform possible long-term impacts of different change scenarios. While calibration to establish model credibility is essential, ability to correctly simulate relative changes is most important.

Model Conceptual Diagrams

Model conceptual diagrams for the HSPF and SWAT models are presented in Figure 4 and Figure 5. The diagrams conform to the scope and schematic approach that has been proposed by Clark et al. (2008) as a means of diagnosing differences in hydrologic model structures.

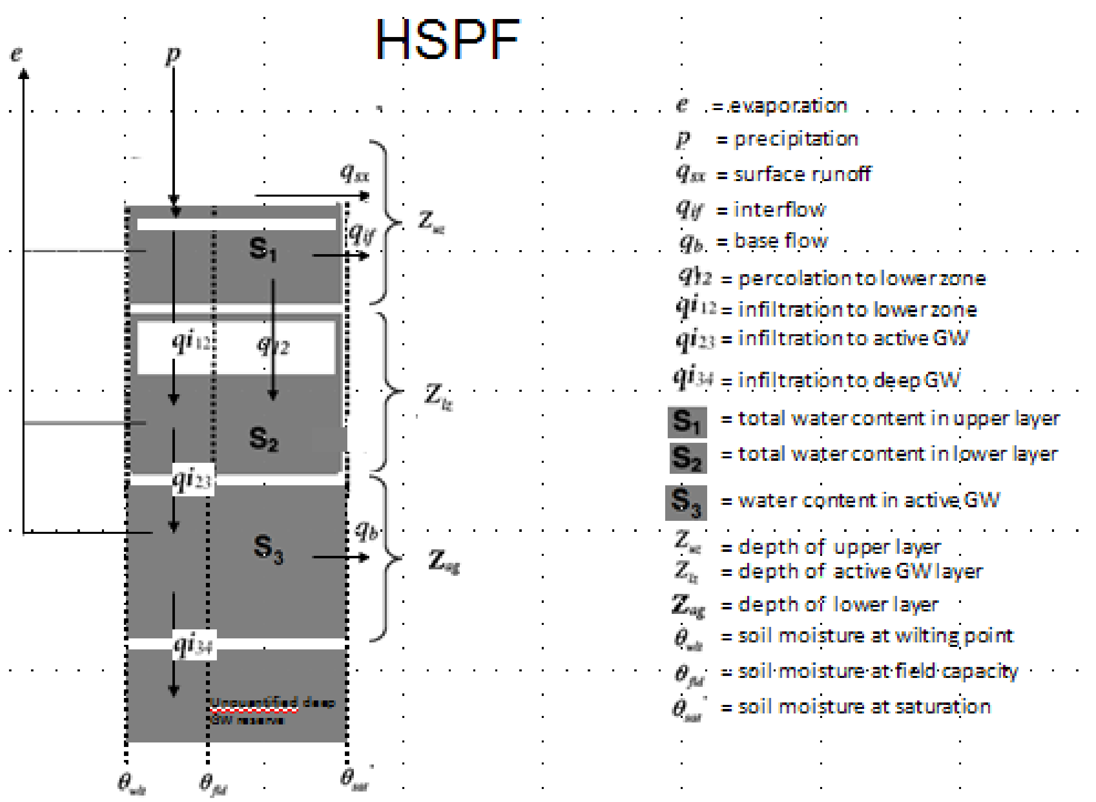

Figure 4. HSPF conceptual diagram.

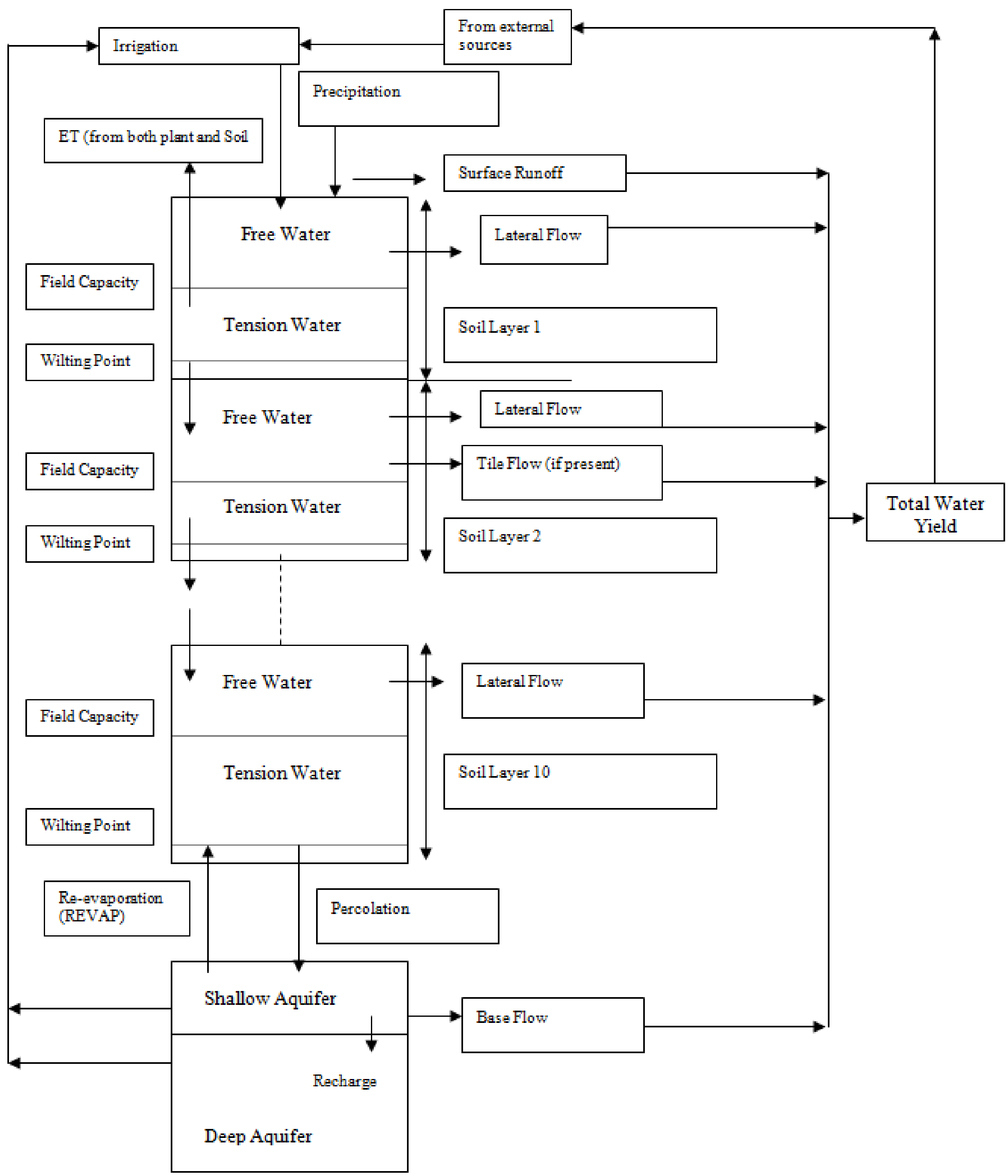

Figure 5. SWAT conceptual diagram.

Important features of HSPF model structure include the following:

1. Water movement is not computed using a scheme that differentiates between free water and tension water.
2. Compartments include upper zone, lower zone, active groundwater and deep groundwater. Movement of water to deep groundwater is uni-directional; deep groundwater is a sink with unspecified depth or volume.
3. During precipitation events infiltration fluxes are calculated that move water from the upper zone, to the lower zone, to active groundwater, and to deep groundwater.
4. During period of no precipitation the opportunity for percolation from the upper zone to the lower zone is simulated.
5. Lateral fluxes include surface runoff, interflow from the upper zone, and base flow from the active groundwater.
6. Evaporation fluxes are computed from the upper zone, the lower zone and from active groundwater.

Important features of SWAT model structure include the following:

1. SWAT is a watershed-scale, continuous-time model that operates on a daily time step and capable of continuous simulations over long time periods.
2. The model is process based, for the most part and is designed to predict the effects of land use and land management changes on the hydrology and associated water quality in the water bodies of the region.
3. In order to adequately simulate hydrologic processes in a basin, the basin is divided into subbasins through which streams are routed. The subunits of the subbasins are referred to as hydrologic response units (HRUs) which are the unique combination of soil and land use characteristics and are considered to be hydrologically homogeneous. The model calculations are performed on a HRU basis and flow and water quality variables are routed from HRU to subbasin and subsequently to the watershed outlet.
4. The SWAT model simulates hydrology as a two-component system, comprised of land hydrology and channel hydrology. The land portion of the hydrologic cycle is based on a water mass balance.
5. Within each HRU, the major hydrological processes simulated by SWAT include canopy interception of precipitation, evapotranspiration, infiltration, surface runoff, lateral flow (subsurface flow), return flow (shallow ground water flow or baseflow), soil moisture redistribution, and percolation to deep aquifer.
6. Water enters the SWAT model's watershed system boundary predominantly in the form of precipitation. Precipitation is partitioned into different water pathways depending on system characteristics.
7. The water balance of each HRU in the watershed contains four storage volumes: snow, the soil profile (0-2 m), the shallow aquifer (2-20 m) and the deep aquifer (>20 m). The soil profile can contain several layers.

8. The soil-water processes include infiltration, percolation, evaporation, plant uptake, and lateral flow. Surface runoff is estimated using the SCS curve number or the Green-Ampt infiltration equation. Percolation is modeled with a layered storage routing technique combined with a crack flow model. Potential evaporation can be calculated using Hargreaves, Priestly-Taylor or Penman-Monteith method (Arnold et al., 1998).

Performance Metrics and Acceptance Criteria

Given the considerations listed above, quantitative acceptance criteria will be expressed in relative, rather than absolute form. That is, relevant calibration outputs will be ranked on a scale ranging from "poor" to "very good." Calibration will strive to obtain the best fit possible; however, specific values of quantitative measures will not be proposed to define whether results should be accepted or rejected. Rather, the level of uncertainty determined in calibration and validation will be documented to aid decision makers in interpretation of results.

Quantitative measures, sometimes referred to as calibration criteria, include the relative percent error between model predictions and observations as defined generally below:

$$E_{rel} = \frac{\Sigma |O - P|}{\Sigma O} \times 100,$$

where *Erel* = relative error in percent. The relative error is the ratio of the absolute mean error to the mean of the observations and is expressed as a percent. Relative percent error values provide a good metric for evaluating difference in magnitude between observed and simulated values. A relative error of zero is ideal. Additional statistics that will be applied include the correlation coefficient (R) and its squared value, the coefficient of determination (R^2), where

$$R = \frac{\sum (O_i - \overline{O}) \cdot (P_i - \overline{P})}{\sqrt{\sum (O_i - \overline{O})^2 \cdot (P_i - \overline{P})^2}} = \frac{\sum O_i \cdot P_i}{\sqrt{\sum O_i^2 \cdot \sum P_i^2}},$$

where the overbar indicates the sample mean. The coefficient of determination values provided a good metric for evaluation correlation between observed and simulated values.

For hydrology and the water balance, percent error tests will be applied to the following components:

- Total flow volume
- 10% high flows
- 50% low flows
- Seasonal flow volumes

These tests are relevant to monthly and annual values. General calibration/validation targets for percent error consistent with current best modeling practices are shown in Table 2.

We anticipate that generating the performance metrics that are described above will satisfy the study objectives. However, if these the results of these evaluations suggest a need for more a more robust collection of metrics, we will expand the analyses to include the Nash-Sutcliff coefficient of model fit efficiency (COE) for high flows and the Modified NS test for low flows.

Table 2. General percent error calibration/validation targets for watershed models applicable to monthly, annual, and cumulative values (Donigian, 2000).

	Relative Percent Error		
	Very Good	**Good**	**Fair**
Hydrology/Flow	>10	10-15	15-25

There is also an interest in extreme high and low flows. Answering this study question requires calibration to daily flows, rather than just monthly and annual values. Figure 6 summarizes R and R^2 ranges for the evaluation of daily and monthly flows.

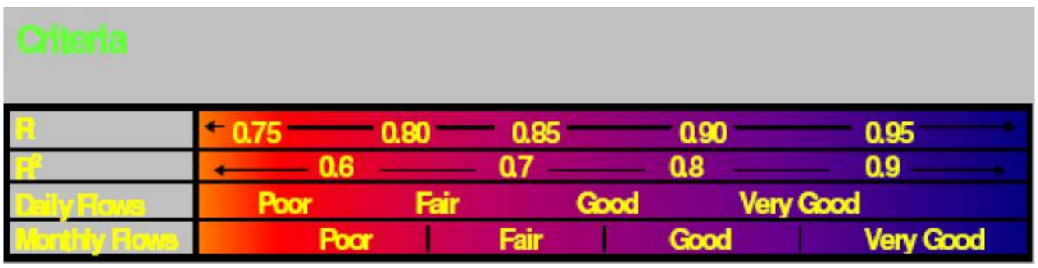

Figure 6. R and R^2 value ranges for model performance (Donigian, 2000)

The Cadmus Team will document model performance over the calibration period in the technical reports, using the quantitative measures of accuracy documented above.

Performing quantitative uncertainty analysis for complex models such as HSPF and SWAT is resource-intensive, and we do not believe that the necessary investment is justified for EPA in a study such as this which is designed to evaluate relative impacts. However, based on decades of experience in applying the models, the Project Team will provide a qualitative assessment of overall model uncertainty, as well as the relative degree of uncertainty that is associated with various components of each of the models. Based on our professional judgment we will compare and rank the various sources of uncertainty.

A8 Special Training Requirements/Certification

Contractor personnel involved in this project hold advanced degrees from academic programs that are well known for excellence in geology, water quality management and policy, and watershed modeling. Contractor personnel have professional experience in hydraulic fracturing, watershed characterization, data management, analysis of water quality data, geospatial analysis, and water quality modeling.

No special training or certification is required for participants in this project beyond the already high degree of academic training and professional experience in water quality obtained to fulfill job requirements commensurate with their current assignments.

A9 Documentation and Records

All project documents will be stored in electronic form on Cadmus, AQUA TERRA, and TAMU computer servers. Any documents received only as hardcopy will be scanned and converted to PDFs, and stored with all other electronic files. All project documents will be stored on servers with regularly-scheduled backup. Cases in which a file originating from an external source needs to be manipulated (e.g., formatted for model input), an original, non-edited version of the file will be retained. Project notebooks will be used to log progress and project activities.

Throughout the project (e.g., as task are completed), AQUA TERRA and TAMU will provide Cadmus with final copies of electronic files. At the conclusion of the project, Cadmus will transfer all project files to EPA via an FTP site or media (e.g., DVD, portable hard drive, etc.). Cadmus will maintain electronic archives of all project files for at least five years following the task order end date.

Cadmus will control the review, revision, and distribution of the most recent version of the QAPP. Document control information (i.e., version and date) will appear in the upper right hand cover of each page of the QAPP. A signed approval form will accompany the approved QAPP. The final approved version of the QAPP will be distributed by the Cadmus Project Manager to all project staff. Any revision to the approved QAPP will be circulated to EPA and contractor personnel for review and approval. Documentation of approval is evidenced by signatures.

Section B – Measurement and Data Acquisition

B1 Sampling Process Design

This section pertains to primary data collection and is therefore not applicable to this project.

B2 Sampling Methods

This section pertains to primary data collection and is therefore not applicable to this project.

B3 Sample Handling and Custody

This section pertains to primary data collection and is therefore not applicable to this project.

B4 Analytical Methods

This section pertains to primary data collection and is therefore not applicable to this project.

B5 Quality Control

This section pertains to primary data collection and is therefore not applicable to this project.

B6 Instrument/Equipment Testing, Inspection, and Maintenance

This section pertains to primary data collection and is therefore not applicable to this project.

B7 Instrument/Equipment Calibration and Frequency

This section pertains to primary data collection and is therefore not applicable to this project.

B8 Inspection/Acceptance of Supplies and Consumables

This section deals with primary data collection and is therefore not applicable to this project.

B9 Non-direct Measurements

This project will require the use of secondary data, also referred to as non-direct measurements. As also discussed in Sections A7 and D1, data will be obtained from qualified sources, including peer-reviewed journals and report developed by federal and state government agencies, academic institutions, or local agencies. Data sources will be appropriately cited in project deliverables.

The Susquehanna and Upper Colorado River Basin models developed for the EPA "20 Watersheds Study" (Tetra Tech, 2011) serve as the starting point for this study. As is this case for the current study, the acceptance criteria for input data used to develop these models were held in common and are described in the QAPP that was developed for the previous study (Tetra Tech, 2011).

Additional input data are required for the 'baseline,' 'current,' and 'future' versions of the Susquehanna and Upper Colorado Models that will be used to meet the objectives of the HF study. These include:

- Characterization and operation data for major reservoirs.
- Surface water and groundwater usage and return flow information (volume, timing, location) for major usage categories (public water supply, irrigation, industrial water supply, irrigation, thermoelectric cooling water, other mining).
- Surface and groundwater usage and return flow information (volume, timing, location) for HF operations (withdrawal, disposal, recycling).
- Flow criteria data for environmental flow management.
- Projected land use and population data for 'future' simulations.

- Projected meteorological data for 'future' simulations.
- Current HF well locations.
- Thermal maturity of natural gas deposits.
- Depth to productive natural gas deposits.
- Thickness of natural gas deposits.
- Land surface slope.
- Locations of roads.
- Locations of natural gas pipelines.
- Current land use.
- Hydrography.

Data to be used as input to the modeling effort will be judged acceptable for their intended use if they meet acceptance criteria. The Cadmus Team, in consultation with the EPA TOM, will determine the factors to be evaluated to determine whether the data provided in secondary sources are acceptable for use in developing, calibrating, or testing the models for this project. Acceptance criteria that will be used for this project will include data reasonableness, completeness, representativeness, and comparability.

- Data reasonableness: Data sets will be checked for reasonableness. Graphical methods will be used to evaluate potential anomalous entries that may represent data entry or analytical errors. In addition, all dates will be checked through queries to ensure that no mistyped dates (e.g., 8/24/1900) and corresponding information are loaded into the models without clarification from the agency from which the data were collected.
- Data completeness: Data sets will be checked to determine the extent of gaps in data in space and time. In any complex model study, it is inevitable that there will be some data gaps. These data gaps and the assumptions used in filling the gaps will be documented for inclusion in the technical reports.
- Data representativeness: Data sets will be evaluated to ensure that the reported variable and its spatial and temporal resolution are appropriate for the current project. For example, data sets must be able to be reasonably aggregated (or disaggregated) to represent conditions in individual watershed model segments and must be representative of conditions during the simulation periods.
- Data comparability: Data sets will be checked with respect to variables of interest, commonality of units of measurement, and similarity in analytical and QA procedures. The Cadmus Team will ensure additional comparability of data by similarity in geographic, seasonal, and sampling method characteristics.

Though not identified as explicit acceptance criterion for this project, priority will be given to peer-reviewed data and data that have undergone documented QA procedures by their source. Acceptance criteria will be obtained from any existing QAPPs, sampling and analysis plans, standard operating procedures (SOPs), laboratory reports, and other correspondence for a given source of data, if available. The data assessment and quality guidelines associated with a given type of measurement will be developed from these sources and included in the documentation.

B10 Data Management

Consistent data management procedures will be used for each project task.

All original data sources will be documented to identify the website or contact person that provided the data, data query parameters, and data request correspondence. Copies of all original data files will be retained.

Data preparation, manipulation, and analysis steps will be documented.

Data in hard copy form will be manually entered into Excel spreadsheets or model input files. Ten percent of the data will be spot-checked to ensure accuracy. If errors are detected during the spot-check, the entries will be corrected. Detection of an error will prompt a more extensive inspection of the data, which may lead to a 100% check of the dataset if multiple errors are found. Source documentation used for manually entered data will be scanned, converted to PDFs, and electronically stored with all other electronic files.

Model inputs and outputs, as well as any other data calculations, will be verified by initial and final reviews. This will include checking to ensure that the model input files contain the intended input values, and that model outputs correspond to the correct set of inputs.

Data will be stored and organized so that files are grouped by project task, and files names and types are consistent. Backup files for the project will be created on a network server on a daily basis to prevent data losses.

Section C – Assessment and Oversight

C1 Assessments and Response Actions

Work conducted for this project will undergo technical review by personnel at Cadmus (scenario development calculations), AQUA TERRA (HSPF modeling), and Texas A&M University (SWAT modeling) who were not directly involved with the data calculations and modeling.

The Cadmus Project Manager and the AQUA TERRA and Texas A&M University lead modelers have responsibility for monitoring project activities and identifying or confirming any quality problems. Any problems will be brought to the attention of the Cadmus, AQUA TERRA, and Texas A&M University QA Officers, who will initiate corrective actions, document the nature of the problem, and ensure that the recommended corrective action is carried out.

Many of the technical problems that might occur can be solved on the spot by the technical staff, for example, by modifying the technical approach or correcting errors or deficiencies in documentation. Immediate corrective actions form part of normal operating procedures and are noted in records for the project. Problems that cannot be solved in this way require more formalized, long-term corrective action. If quality problems that require attention are identified, the QA Officers will determine whether attaining acceptable quality requires either short- or long-term actions.

The Cadmus Project Manager will perform surveillance activities to ensure that management and technical aspects are being properly implemented according to the schedule and quality requirements specified in this QAPP. These surveillance activities will include assessing how project milestones are achieved and documented, corrective actions are implemented, budgets are adhered to, reviews are performed, and data are managed. The Cadmus Project Manager will also use written responses (by AQUA TERRA and Texas A&M University) to a technical systems assessment form to evaluate subcontractors for implementation and conformance to the requirements of this QAPP. The technical systems assessment will include assessment of data collection activities, documentation, quality checks, record management, and reporting.

C2 Reports to Management

Documentation to be submitted for quality assurance and review purposes includes:

- Draft and final QAPP;
- Monthly progress reports;
- Completed technical system audit forms for each model;
- Journal manuscripts; and
- Final model and other data files (upon completion of the project or upon request of EPA).

Section D – Data Validation and Usability

D1 Data Review, Verification, and Validation

The quality of data used for, and generated during, the modeling will be reviewed and verified at multiple levels by Cadmus, AQUA TERRA, and Texas A&M University technical staff and QA Officers. Data review, verification, and validation will focus on the acceptability of the input data used for calculations and modeling. All original and modified data files will be reviewed for input, handling, and calculation errors. Any potential issues identified through this review process will be evaluated and, if necessary, data will be corrected and analysis will be carried out using corrected data.

D2 Verification and Validation Methods

The integrity of model output data will be verified and validated through a review of data files by AQUA TERRA, and Texas A&M University (TAMU) technical staff. Reviews may include a thorough evaluation of content and/or a "spot-check" of calculated values. Should a review identify an aberration from established data quality objectives and criteria (Section A7), the reviewer will notify those responsible for taking corrective actions. The Cadmus, AQUA TERRA, and Texas A&M University QA officers will be notified if corrective action is potentially required.

Evaluation of whether model components and their outputs are satisfying the DQOs will be an ongoing process for QA personnel during the model calibration and validation stage of the project. In-progress assessments of validation issues will be discussed between a team including both technical and QA representatives from EPA, Cadmus, AQUA TERRA and TAMU. The authority for resolving validation issues will be the Quality Assurance Officer for EPA ORD (see Section A4).

The results of performing evaluations will be logged and integrated into the project documentation at the conclusion of the project, as well any corrective actions that were implemented

D3 Reconciliation with User Requirements

The value of the information generated by this project will be determined by evaluating data quality and by comparing methods/results with published data and scientific literature. Any data quality issues that are determined to affect the conclusions or recommendations of this project will be discussed in the journal articles.

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