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Characterization of Methylmercury Loads for Irrigated Agriculture in the Delta

Final Report

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EXECUTIVE SUMMARY

This work presents the characterization of mercury (total and methylmercury) in inflows, outflows, and drains from selected agricultural fields in the Sacramento-San Joaquin River Delta, based on sampling performed in the irrigation season of 2014 and a limited amount of sampling in the wet season of 2015. This work was performed by Tetra Tech staff with the support of staff from the US Environmental Protection Agency Region 9 (Valentina Cabrera-Stagno) and the Central Valley Regional Board (Janis Cooke).

The sampling was focused on non-rice irrigated agriculture and included the following crops: alfalfa, pasture, corn and tomato. The California Regional Water Quality Control Board, Central Valley Region (Central Valley Water Board) has established a Total Maximum Daily Load (TMDL) for methylmercury in Delta, driven by elevated levels of mercury in fish, and the consequent risk to humans and wildlife (CVRWQCB 2010; 2011). As part of this TMDL agricultural sources are a potential source to be quantified. The TMDL states that agricultural and wetland managers are responsible only for methylmercury that is added by their activity or land use, not methylmercury in source water. Thus, the data collection was intended to evaluate agricultural inflow as well as drainage. The general objective of this work was to characterize the methylmercury loading from non-rice irrigated agriculture. Sites were identified by the Regional Board through outreach to various agricultural coalitions in the Delta, representing different crop types, and data collection was coordinated with irrigation events in individual farms. Two study areas were near Dixon, one on Staten Island, and one on the McCormick-Williamson Tract which is located near Walnut Grove, CA in proximity to the Staten Island site. At each of these study areas four samples were collected at three separate locations. The samples collected were tested for dissolved organic carbon (DOC), methylmercury (MeHg), total mercury (Hg), and total suspended solids (TSS). Electrical conductivity (EC) was measured as a surrogate for dissolved solids, and an indicator of evapoconcentration of applied irrigation water. The locations where the samples were taken from at each site were the inflow, outflow (or the tail water), and drain (or discharge channel, where drain water from multiple fields flowed into).

The analysis approach compared different station types (inflow, outflow, or drain) with a focus on individual water quality metrics, and on selected ratios such as MeHg/Hg, Hg/TSS, Hg/DOC, etc. Our goal was to examine whether the changes in the ancillary parameters across sites could be related to the Hg and MeHg changes. This was done by comparing ratios of outflow:inflow concentrations and also drain:inflow concentrations. For developing estimates of loads of total Hg and MeHg from individual fields, we made reasonable assumptions of inflows and outflows to calculate the net loads.

The following key observations were obtained from an evaluation of the data:

- It is clear from the data that there is MeHg production in fields, because the concentrations are much higher than would be predicted by evapoconcentration of water alone. MeHg concentration elevation is strongly correlated to DOC elevation in field outflows, and could be tied to an added transport pathway on DOC or to the stimulation of methylation due to the presence of DOC. An example plot showing this result is reproduced as Figure ES-1.

- Total Hg concentrations are elevated in the outflows, and this process is was weakly correlated with increased TSS levels in outflows. An example plot showing this result is reproduced as Figure ES-2. No statistically significant correlation was observed.

- Fields are sinks for MeHg and total Hg during summer because of field hydrology, i.e., the outflow volumes are much smaller than the inflow volumes. There is some potential for remobilization in winter, where the concentrations of MeHg and total Hg are elevated, and the inflow loads can be considered to be near zero (i.e., only from Hg and MeHg in precipitation). However, in this study there were too few measurements following rain events to attempt a load estimation for winter.

- The runoff rates—water applied in excess of evapotranspirative demand—used here were estimates in the absence of observed data on hydrology. They are considered to span a reasonable range, and the calculation of mostly negative export for both Hg and MeHg in the summer season is considered credible. The total water application rates (obtained by adding evapotranspiration, runoff and percolation, the latter two quantities assumed at reasonable levels) are consistent with large scale irrigation water application in California.

- Drains are integrators across multiple fields and looking at a single field or crop on an island provides only very preliminary and incomplete data. They were not used for a quantitative analysis in this work, although the concentrations indicate lower values than the outflow locations, suggesting the presence of significant removal and settling mechanisms in the drains. For MeHg and total mercury it could be in the form of particulate settling or volatilization, for MeHg it could be demethylation.

The data and analysis presented in this document add significantly to the body of literature on mercury in irrigated non-rice agriculture, which represents a large fraction of the Delta island land use. However, the data are for a single season, and future work may enhance this study by consideration of additional sites, direct characterization of field hydrology, and performance of year round sampling to characterize annual mercury budgets. Based on the findings of studies such as these, in future years the Regional Water Board may choose to reevaluate various components of the TMDL, such as load targets, water quality targets, and compliance dates.

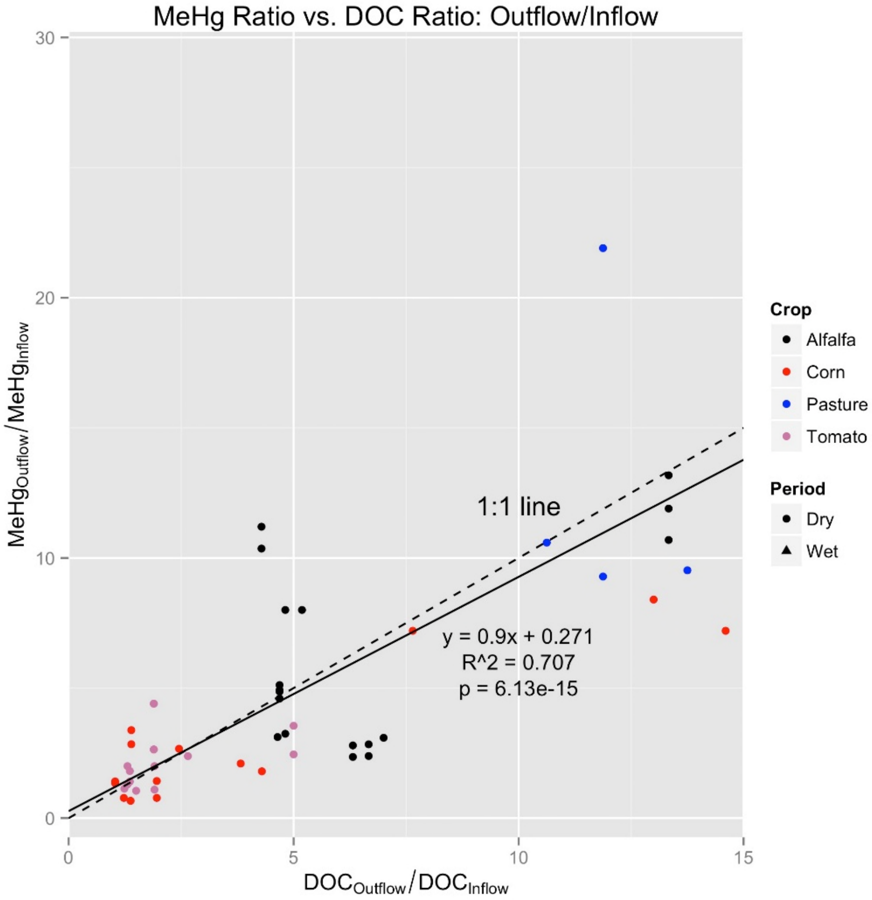

Figure ES-1 Ratio of MeHg in outflow:inflow as a function of DOC outflow:inflow. Symbol colors indicated different crop types. Note the range in the ratios in both the x- and y-axes, indicating significant elevation of both DOC and MeHg in the outflows compared to inflows. Dashed line reflects the 1:1 ratio; solid line shows best fit linear regression (statistically significant).

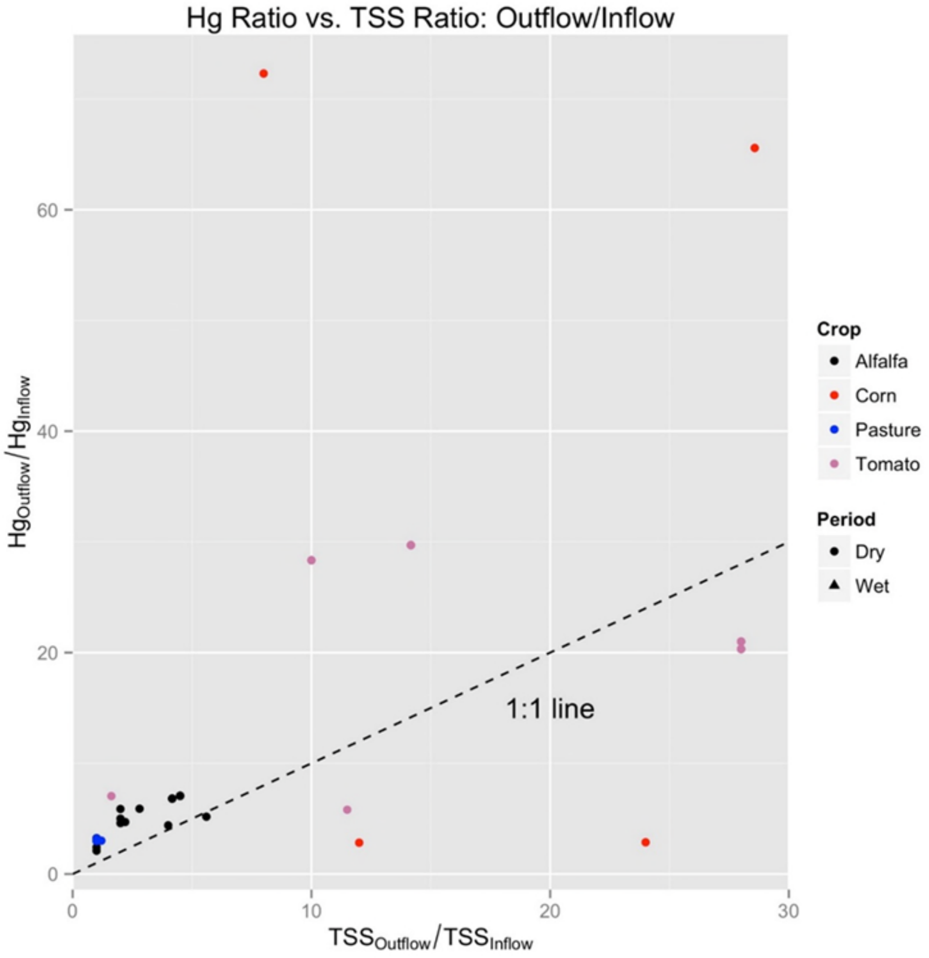

Figure ES-2 Ratio of total Hg in outflow:inflow as a function of TSS outflow:inflow. Note the range in the ratios in both the x- and y-axes, indicating significant elevation of both TSS and Hg in the outflows compared to inflows. No statistically significant correlation was observed.

1 INTRODUCTION

The California Regional Water Quality Control Board, Central Valley Region (Central Valley Water Board) has established a Total Maximum Daily Load (TMDL) for methylmercury in the Sacramento-San Joaquin Delta Estuary (the Delta), driven by elevated levels of mercury in fish, and the consequent risk to humans and wildlife (CVRWQCB 2010; 2011). Reductions in water column methylmercury are required to reduce methylmercury concentrations in fish. Based on correlations between water column methylmercury and concentrations in largemouth bass, a fish tissue goal of 0.24 mg/kg, and allowing for a 10% factor of safety resulted in an implementation goal for unfiltered water of 0.06 ng/l methylmercury, to be applied on an annual basis. The analysis divided the Delta into eight subareas based on the hydrologic characteristics and mixing of the source waters (Figure 1-1), compliance with the methylmercury target is met in one of these subareas (Central Delta), and nearly met in another (West Delta), with the remaining six subareas exhibiting higher concentrations.

At the time of the Central valley TMDL development, average annual methylmercury inputs and exports were estimated for water years 2000 to 2003. Sources of methylmercury in the Delta include wetland and in-channel sediments, municipal and industrial wastewater, agricultural drainage, and urban runoff. Methylmercury load allocations were made in terms of the existing assimilative capacity of the different Delta subareas. The existing average methylmercury concentration in water in each Delta subarea was compared to the TMDL target of 0.06 ng/l, and a reduction proposed for each subarea. Loads of methylmercury from point and nonpoint sources and tributary inputs need to be reduced in proportion to the desired decrease in concentrations to achieve the 0.06 ng/l target for each subarea.

Independent of the Central Valley effort, the San Francisco Bay Regional Water Quality Control Board (San Francisco Water Board) identified total mercury loads through the Delta as an important source of mercury to San Francisco Bay and, the mercury TMDL for San Francisco Bay, assigned the Central Valley a load reduction of 110 kg/yr. To address this need, the Central Valley TMDL considers both methylmercury and total mercury sources in the Delta. Reductions in total mercury loads are needed to reduce aqueous methylmercury in the Delta, to maintain compliance with the USEPA's criterion of 50 ng/l, and to comply with the San Francisco Bay mercury control program.

The implementation of the Central Valley TMDL consists of a nine-year Phase 1 (2011-2020) (CVRWQCB, 2012). Phase 1 focuses on studies and pilot projects to develop and evaluate management practices to control methylmercury. Based on the findings of studies performed during Phase 1, the Regional Water Board may choose to reevaluate various components of the TMDL, such as load targets, water quality targets, compliance dates, etc. Thus, the primary focus of Phase 1 is to improve our understanding of mercury cycling and potential controls, to better support future regulatory and policy actions on this issue.

The specific focus of this effort is to improve our understanding of the loads of methylmercury from agricultural lands in the Delta. For the Delta mercury TMDL, Regional Board staff estimated methylmercury loads contributed by irrigated agriculture in the Delta and Yolo Bypass using data available at the time. The agriculture dataset was comprised of methylmercury concentration data collected from five agricultural drains within the Delta on between one and five sampling events, depending on the drain (total = 12 samples). No samples in the TMDL dataset were collected in Yolo Bypass. The TMDL states that agricultural and wetland managers are responsible only for methylmercury that is added by their activity or land use, not methylmercury in source water. Thus, the data collection was intended to evaluate agricultural inflow as well as drainage. The general objective of this work was to characterize the methylmercury loading from non-rice irrigated agriculture, because other recent studies in the Delta have focused on mercury exports from rice agriculture (Bachand et al., 2014; Windham-Myers et al., 2014; Alpers et al., 2014). This study extends a data collection effort on islands performed by Heim et al. (2009).

This work was performed by Tetra Tech staff with the support of staff from the US Environmental Protection Agency Region 9 (Valentina Cabrera-Stagno) and the Central Valley Regional Board (Janis Cooke). Sites were identified by the Regional Board through outreach to various agricultural coalitions in the Delta, representing different crop types and soil-type characteristics, and data collection was coordinated with irrigation events in individual farms. Data were collected for unfiltered mercury (or Hg) and methylmercury (or MeHg); and for the following ancillary parameters: dissolved organic carbon (DOC), total suspended solids (TSS), electrical conductivity (EC), and dissolved oxygen (DO). The remainder of this report describes the field and sample collection activities (Chapter 2), the analysis approach used (Chapter 3), results and analysis of the mercury and ancillary parameter data (Chapter 4), and a discussion the results and next steps (Chapter 5). The work only considered MeHg and constituent export during the irrigation season. In studies of rice export characteristics in the Yolo Bypass, Bachand et al. (2014) identified seasonal storage and release of methylmercury from rice fields during the non-irrigation season. Seasonal effects would be expected for other cropping systems as well.

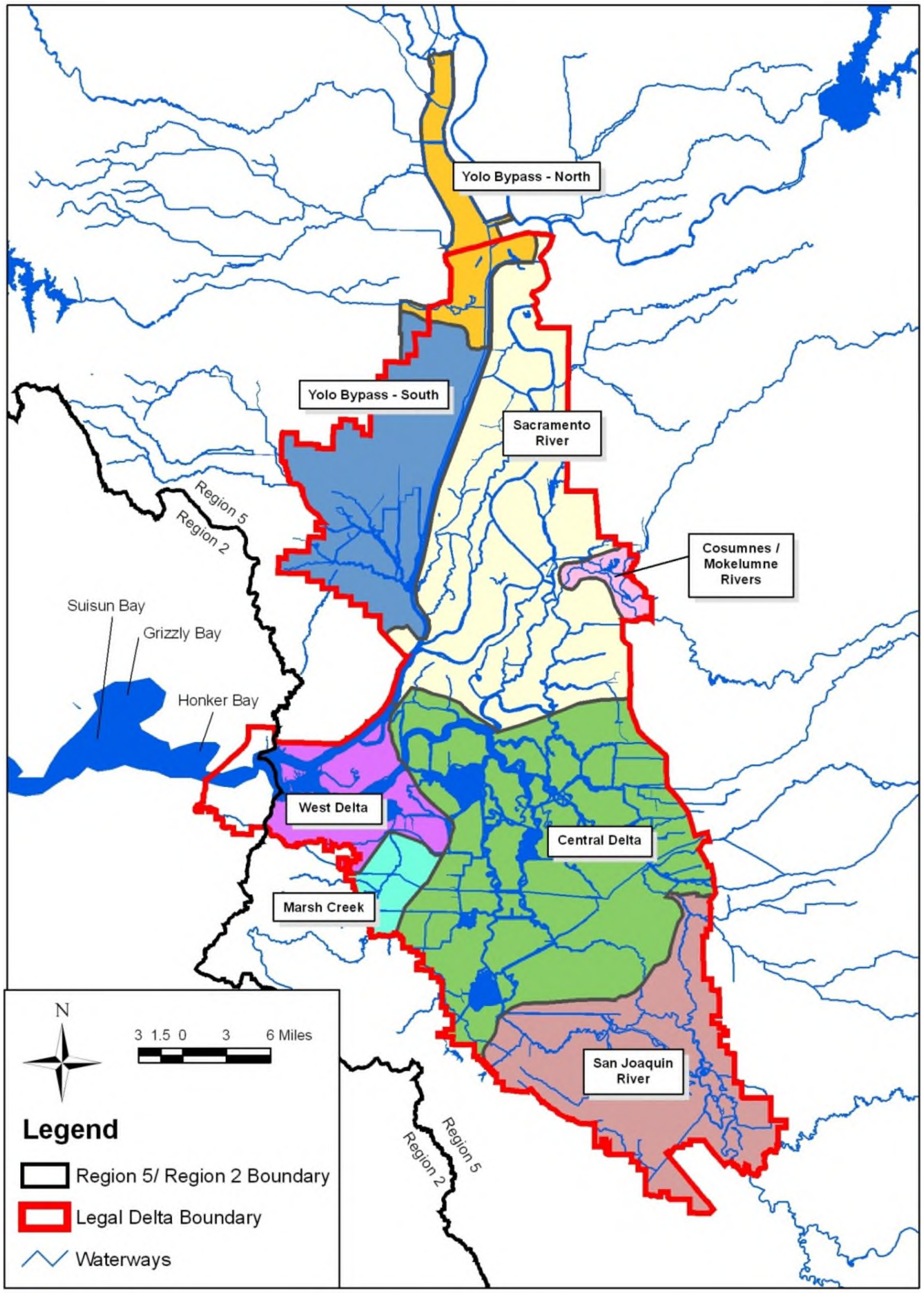

Figure 1-1 Delta Sub-areas

2 FIELD AND LABORATORY ACTIVITIES

This section provides an overview of the sample collection and laboratory analysis conducted over a roughly 9 month period from June 2014 to February 2015. The sampling was largely focused on the dry season (generally to the end of September), during which irrigation water is applied in the Delta, although a few samples were collected following winter precipitation events for comparison (in December 2014 and February 2015). Wet weather sampling was also limited by the extremely unusual dry conditions encountered in water year 2015, with almost zero precipitation in January.

2.1 SITE DESCRIPTION

Samples were collected from areas in the Sacramento Delta, near Dixon and on and near Staten Island (Figure 2-1). Two study areas were near Dixon, one on Staten Island, and one on the McCormick-Williamson Tract which is located near Walnut Grove, CA in proximity to the Staten Island site. The Dixon site had two different agricultural fields near each other along Interstate 80N. For brevity the McCormick-Williamson Tract is subsequently referred to as the McCormick site.

2.2 SAMPLING OVERVIEW

At each of these study areas four samples were collected at three separate locations. The samples collected were tested for DOC, MeHg, total Hg, and TSS. The locations where the samples were taken from at each site were the inflow (i.e., the source water, or SW in the sample codes), outflow (the tail water, or TW in the sample codes), and drain (discharge channel, or DC). There were four types of crops/fields the samples were taken from: corn (McCormick), alfalfa (All Sites), pasture (Staten Island), and tomato (Dixon, Staten Island).

All dry weather sampling was coordinated with irrigation events, i.e., sampling generally occurred one to two days after the initiation of irrigation, when water was likely to be present in outflow channels. Wet weather events were planned following rainfall events of magnitude greater than 0.1 inches and probability greater than 70%.

Examples of site locations, indicating visually the typical sizes of the channels sampled, as well as the turbidity in the water, are shown in Figure 2-2 to Figure 2-17. These photographs provide a visual description of the types of waters encountered, but are not exhaustive with respect to the sites, crops, and specific conditions during sampling.

2.3 SAMPLE COLLECTION

When sampling the "clean hands dirty hands" method was used for total and methylmercury (USEPA Method 1630 and Method 1631). Pre-cleaned sample bottles were obtained from the laboratories for sampling. Sample bottles for the constituents had preservatives for MeHg (methyl mercury) and total Hg. The DOC (dissolved organic carbon) and TSS (total suspended solids) bottles had to be rinsed three times with the water from the location being sampled before the water was filled for collection. This was done since there were no preservatives in the bottles and to remove any dust particles.

The "clean hands," "dirty hands" method that was used in the sampling collection is as follows: At each location all sampling personnel put on clean gloves before collection of any sample activity. "Dirty hands" must open the cooler or storage container, remove the double-bagged sample bottles from storage, and unzip the outer bag. Next, "clean hands" opens the inside bag containing the sample bottle, removes the bottle, and reseals the inside bag. "Dirty hands" then reseals the outer bag. "Clean hands" unscrews the cap and, while holding the cap upside down, discards the dilute acid solution from the bottle into a carboy. "Clean hands" then submerges the sample bottle, and allows the bottle to partially fill with sample. "Clean hands" screws the cap on the bottle, shakes the bottle several times, and empties the bottle away from the site. After two more rinses, "clean hands" holds the bottle under water and allows bottle to fill with sample. After the bottle has filled and while the bottle is still inverted so that the mouth of the bottle is underwater, "clean hands" replaces the cap of the bottle. In this way, the sample has never contacted the air. Once the bottle lid has been replaced, "dirty hands" reopens the outer plastic bag, and "clean hands" opens the inside bag, places the bottle inside it, and zips the inner bag. "Dirty hands" zips the outer bag.

2.4 SAMPLE PRESERVATION/SHIPMENT/ISSUES

Once sample collection was done the bottles were separated into two coolers. One cooler contained sample bottles for MeHg, DOC, and TSS. These samples were preserved on ice and taken either the same day of the sampling event or the day after for analysis at the EPA Region 9 lab in Richmond, CA. The total Hg samples were also preserved on ice and taken to FedEx for overnight delivery to the Moss Landing Marine Laboratories. There were concerns with the total Hg samples on 6/9-6/10/2014 sampling dates. These samples were collected but issues occurred with the bottle type being used and therefore total Hg for these dates was not included in the final data table. Field team for McCormick site did not have any total Hg bottles for collection on 8/25/14, no samples for this analysis were collected.

2.5 FIELD DATA COLLECTION

For each sampling event a YSI 6920 meter was used to gather measurement on the following constituents in the field DO (dissolved oxygen), pH, Temperature (°C), EC (electrical conductivity), and turbidity shown in Table A-1.

2.6 LABORATORY ANALYSIS

Laboratory analysis was performed by the U.S. Environmental Protection Agency Richmond Laboratory (MeHg, DOC, and TSS), and by the Moss Landing Marine Laboratories (total Hg, and a limited set of samples for MeHg). The following methods were used for the analysis of samples.

DOC: EPA Method 415.3 (samples were filtered prior to analysis)

TSS: Standard Method 2540D

Total Hg: EPA Method 1631E

MeHg: EPA Method 1630

All data were validated independently by Tetra Tech prior to further analysis, and are provided as an electronic appendix to this report. Mercury data (unfiltered total mercury and unfiltered methylmercury) are shown in Table A-2. All detailed laboratory reports and chain of custody forms are also provided as an electronic appendix for future reference.

Figure 2-1 Map Location of Dixon and Staten Island Sites.

Figure 2-2 Dixon 1 Alfalfa field. This is the source water for Dixon 1 Alfalfa field. Picture is from sampling event on 9/10/14. The blue arrow indicates the approximate location of the sampling.

Figure 2-3 Dixon 1 Alfalfa field. This is the tail water for Dixon 1 Alfalfa field. Picture is from sampling event taken place on 9/10/14. Photo shows the outflow being sampled before exiting into the drain towards the drainage channel location of Ulatis Creek.

Figure 2-4 Dixon 3 Tomato field. This is the source water or inflow for Dixon 3 tomato field. Picture is from sampling event taken place on 9/3/14. The blue arrow indicates the approximate location of the sampling.

Figure 2-5 Dixon 3 tomato field. This is the tail water or outflow for Dixon 3 tomato field. Picture is from sampling event taken place on 9/3/14. Photo shows the outflow from the tomato field moving towards the drainage channel. Outflow is moving in the direction of the top left to bottom right of the photo. The blue arrow indicates the approximate location of the sampling.

Figure 2-6 *Dixon 2 tomato field. This is the drainage channel for Dixon 2 tomato field. Picture is from sampling event taken place on 8/5/14. Photo shows the water from the field heading into Ulatis Creek. The blue arrow indicates the approximate location of the sampling.*

Figure 2-7 Dixon 2 tomato field. This is the source water or inflow for Dixon 2 tomato field. Picture is from sampling event taken place on 9/10/14. The blue arrow indicates the approximate location of the sampling.

Figure 2-8 *Dixon 2 tomato field. This is the tail water for Dixon 2 tomato field. Picture is from sampling event taken place on 9/10/14. Photo shows the outflow heading towards the drainage channel in the bottom left. The blue arrow indicates the approximate location of the sampling.*

Figure 2-9 Example of runoff from Staten Island site.

Figure 2-10 McCormick 1 tomato field. This is the tail water for McCormick 1 tomato field. Picture is from sampling event taken place on 7/14/14. Photo shows the outflow heading towards the drainage channel in the bottom left. The blue arrow indicates the approximate location of the sampling.

Figure 2-11 McCormick 1 corn field. This is the source water for McCormick 1 corn field. Picture is from sampling event taken place on 7/28/14. Photo shows the source water heading out into the corn field for irrigation. The blue arrow indicates the approximate location of the sampling.

Figure 2-12 Staten Island 2 pasture field. This is the tail water for Staten Island 2 pasture field. Picture is from sampling event taken place on 6/30/14. Photo shows the outflow heading towards the drainage channel in the bottom right. The blue arrow indicates the approximate location of the sampling.

Figure 2-13 *Staten Island 2 source water. This is the source water for Staten Island 2 pasture field. Picture is from sampling event taken place on 6/30/14. Photo shows the source water channel. The blue arrow indicates the approximate location of the sampling.*

Figure 2-14 *Staten Island 2 alfalfa field. This is an overview of the Staten Island 2 alfalfa field. Picture is from sampling event taken place on 9/2/14.*

Figure 2-15 Staten Island 2 alfalfa field. This is the source water for Staten Island 2 alfalfa field. Picture is from sampling event taken place on 9/2/14. Photo shows the source water channel. The blue arrow indicates the approximate location of the sampling.

Figure 2-16 Staten Island 1 drainage channel for pasture and alfalfa fields. This is the drainage channel for Staten Island 1 pasture and alfalfa fields. Picture is from sampling event taken place on 6/30/14. Photo shows the drainage channel. The blue arrow indicates the approximate location of the sampling.

Figure 2-17 *Staten Island 2 alfalfa field and source water pumping well. This is the pumping well for the source water for Staten Island 2 alfalfa field. Picture is from sampling event taken place on 6/30/14. Photo shows the source water pumping well located in alfalfa field.*

3 ANALYSIS APPROACH

The analysis approach includes the presentation of data across locations during the summer months, comparing different station types (inflow, outflow, or drain) with a focus on individual water quality metrics as reported, and on selected ratios such as MeHg/Hg, Hg/TSS, Hg/DOC, etc. Following this, our goal was to examine whether the changes in the ancillary parameters across sites could be related to the Hg and MeHg changes. This was done by comparing ratios of outflow:inflow concentrations and also drain:inflow concentrations. Where data from multiple locations are compared on a single plot, we use symbology such that additional information on a single data point is visible across plots, i.e., crop type, season, or type of station (inflow, outflow, or drain). The concentration data and ratios provide insight into the mercury transformations that occur in these fields. However, for the specific goal of improving estimates of loads of total Hg and MeHg, we made reasonable assumptions of inflows and outflows to calculate the net loads.

3.1 BOX PLOTS

As the first step in interpreting the data, we show single or paired sets of data as box plots for each site, where a pair of boxes may compare inflow and outflow or drain and inflow. The box plot notation is standard, and shows the 25th, 50th, and 75th percentile of the data, with lines (whiskers) indicating the 10th and 90th percentile. In these plots, when grouped for a single site, the number of data points is often small, and for transparency all data associated with each box are also shown.

3.2 RATIO PLOTS

Here we compare the ratio of mercury species concentrations (either total mercury or methylmercury) at pairs of locations similar to those used for the box plots (outflow over inflow, or drain over inflow), and relate these to the corresponding ratios for EC, DOC, and TSS. The goal of these plots is to show the extent to which the behavior of an ancillary parameter is related to the behavior of mercury. For example, these plots can be used to examine the relationship between the total mercury ratio and the EC ratio, the latter ratio indicating the effect of evapoconcentration in the subject field. If the mercury ratio is higher than the corresponding EC ratio, this implies that a process other than evapoconcentration is increasing concentrations.

3.3 SCATTER PLOTS

We also show the relationship between mercury species and relevant ancillary parameters. These can be used to explore whether there is a correlation between mercury species and an ancillary parameter, such as TSS and total Hg. Because the relationships can be confounded by mixing multiple sites on the same plot, these plots are focused on individual sites.

3.4 CHARACTERISTICS OF WATER TRANSPORT IN FURROW AND FLOOD IRRIGATION

This study focused on furrow and flood irrigation systems. Important to understanding the loading of mercury species, or any constituent, from farm lands is understanding the basic hydrology of the system. The general concept is illustrated in Figure 3-1. When water is applied during an irrigation event (Q_{on}), the water content in the soils (%W) increases from the wilting point to at or above field capacity, a portion percolates into the soil (Q_p), depending upon soil types, agricultural practices and the presence or absence of a confining layer, a portion is lost as outflow or runoff (Q_{off}), and the remainder is transpired by plants or evaporated from the soil surface. Importantly, the runoff process starts and stops soon after water application, whereas the evaporation and transpiration can continue. Evaporation stops once the standing water has disappeared, and transpiration continues while there is water in the root zone. Ideally, the water percolated to the root zone is confined in the root zone and meets the transpiration demands of the crop. Irrigation cycles are repeated during the growing season, often occurring every 10 – 14 days. In this work water quality sampling was performed in the early part of the water application phase in each irrigation event.

The net load during the irrigation season is the difference between the inflow and ouflow loads, with other pathways being considered as losses (either a loss to the atmosphere to the deeper soil layers through percolation).

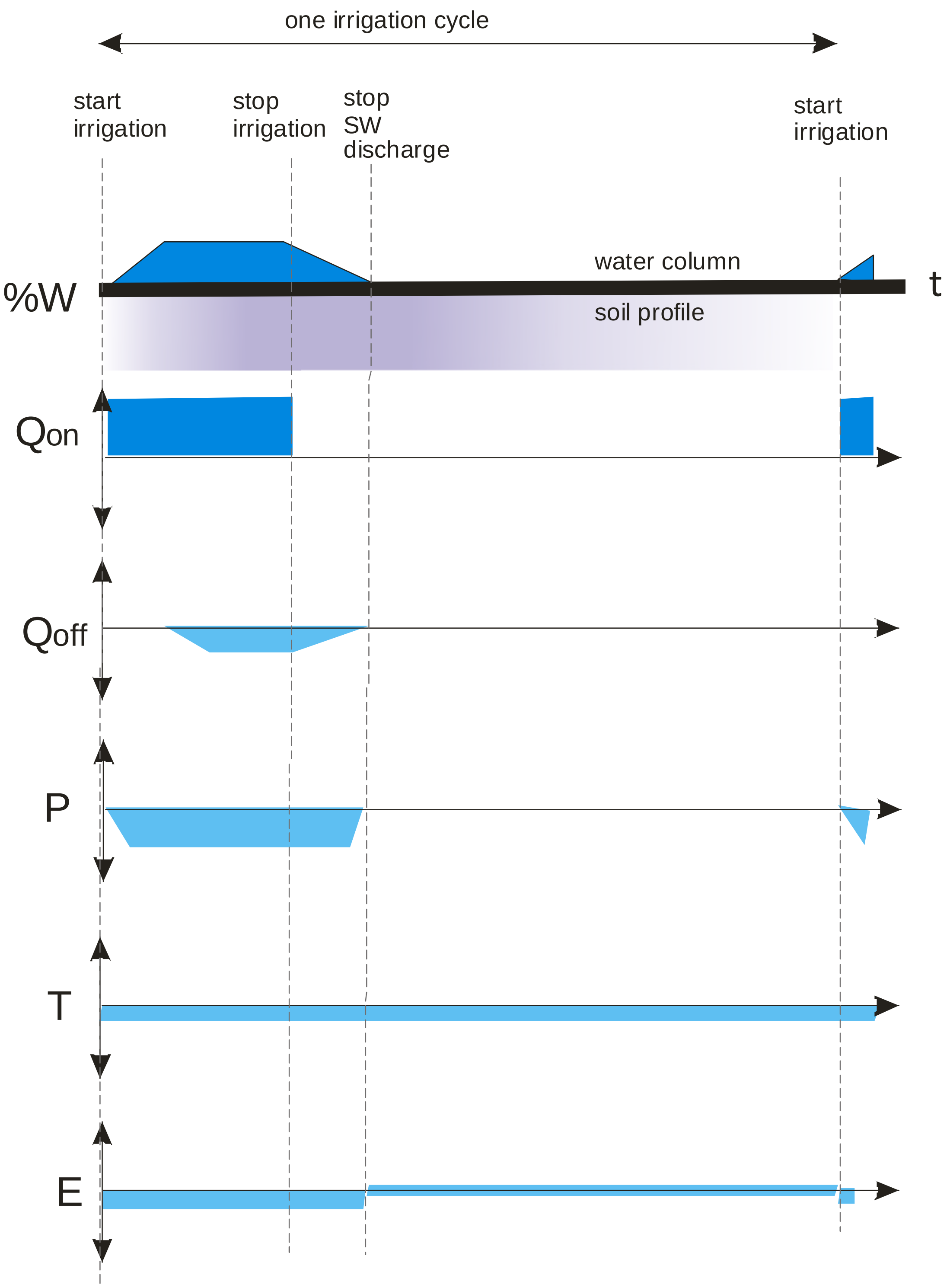

Figure 3-1 Summer hydrology of furrow and flood irrigated farm land. (%W = moisture content; Q_{on} = water application; Q_{off} = runoff; P = percolation; T =transpiration; and E = evaporation)

3.5 ESTIMATION OF MASS LOADS AND TRANSFORMATIONS

The different hydrological components identified in Section 3.4 that are needed for the load calculation were not measured in this work and were not characterized or estimated by the individual growers at these sites. Absent these direct measurements, the hydrological components were estimated from relevant literature values or our professional judgment.

Evapotranspiration was estimated using results of recent regional studies. A recent study evaluated the use of remote sensing technology using the Surface Energy Balance Algorithm for Land (SEBAL) method to compare crop ET against a commonly used model, the California version of the Simulation of Evapotranspiration of Applied Water model (Cal-SIMETAW), for different crops and across five Delta islands (Medellin-Azuara and Howitt, 2013). Values for crops relevant to the present study are shown in Table 3-1. Water application normally exceeds evapotranspiration. Ranges of water application by crop type in the Central Valley are summarized in Cooley (2015), based on Department of Water Resources data, and are reproduced in Figure 3-2. Median values from this source are reproduced in Table 3-1.

Summer estimates of net mass loads due to hydrologic transport were estimated based upon simple irrigation estimates. Surface outflows were estimated to range from 10 – 25% of surface inflows. Depending upon the nature of these soils, percolation was assumed to range from 5-25% of the surface inflows. Thus, the total surface inflow was assumed to equal to ET loss plus outflow plus percolation. Given, a magnitude of ET from Table 3-1, the total inflow could be estimated as well as the outflow. These values, in conjunction with total Hg or MeHg concentrations, could be used to calculate the inflow and outflow loads, as well as the net loads. The upper and lower bounds of each term (runoff percent and percolation percent) were used, resulting in four calculations of load for each sampling event, and reflecting the uncertainty in hydrology at the field level.

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Table 3-1
Crop ET and water application by crop.

	ET-estimated from SEBAL (inches)[1]	**ET-estimated from Cal-SIMETAW (inches)[1]**	**Water Application Depth (median, inches)[2]**	**Ratio (Water Application:ET-SEBAL)**
Alfalfa	35.64	38.57	58.8	1.65
Corn	32.6	28.4	30.0	0.92
Pasture	33.1	44.8	50.4	1.52
Tomato	26.4	28.3	30.0	1.14

[1] Medellin-Azuara and Howitt (2013) Comparing Consumptive Agricultural Water Use in the Sacramento-San Joaquin Delta, UC Davis Center for Watershed Sciences.

[2] Cooley (2015) California Agricultural Water Use: Key Background information.

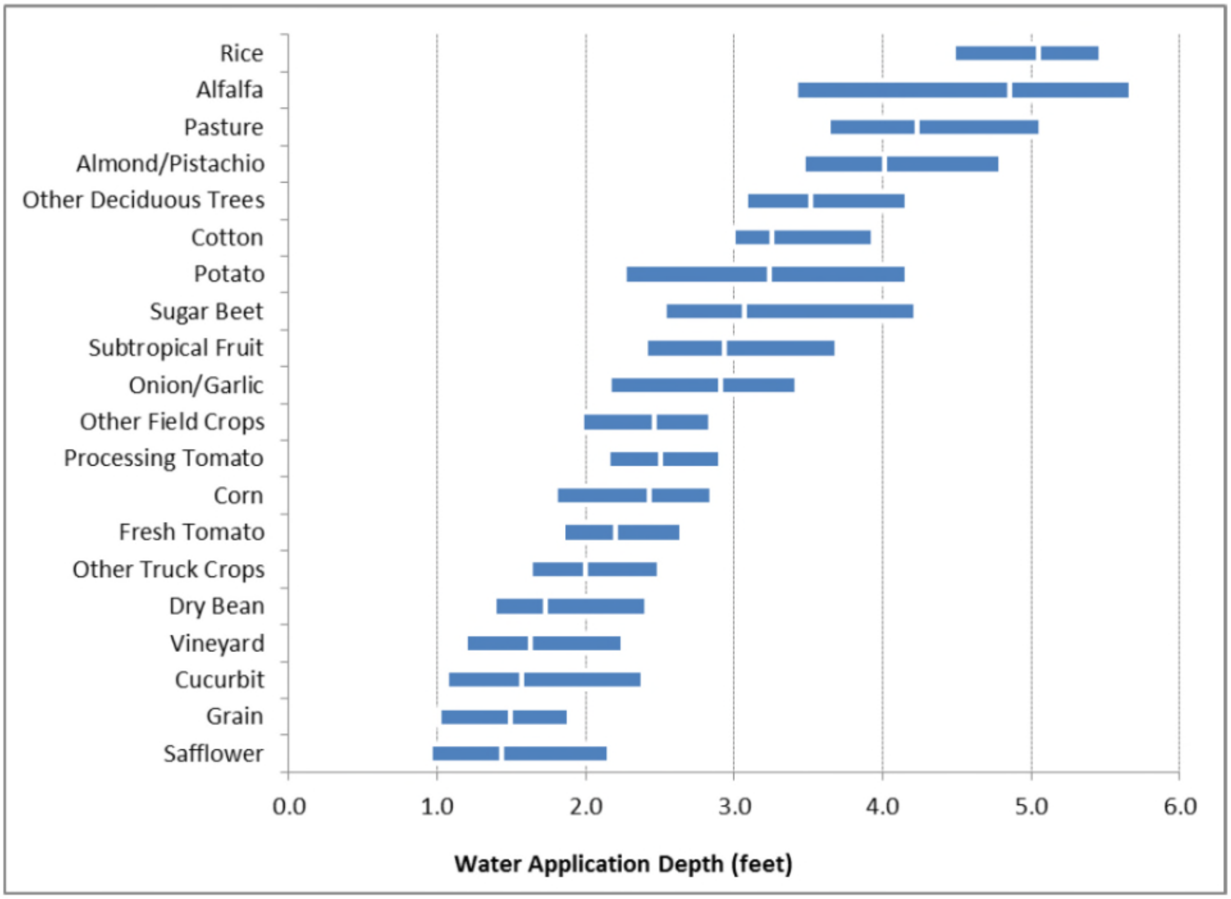


Figure 3-2 Ranges of water application by crop in California (reproduced from Cooley, 2015).

4 RESULTS

The data that are described in this section include the following directly observed quantities: unfiltered total Hg and MeHg, EC, TSS, DOC, and dissolved oxygen (DO); and the following ratios: MeHg over total Hg, total Hg over TSS, and MeHg over DOC. The following nine location-crop combinations were sampled: Dixon 1-Alfalfa, Staten Island 1-Alfalfa, McCormick 1-Corn, McCormick 2-Corn, Staten Island 1-Pasture, Staten Island 2-Pasture, Dixon 2-Tomato, Dixon 3-Tomato, and McCormick 1-Tomato.

In the plots that follow, we first discuss the inflows alone for each of these parameters across the location-crop combinations. We then consider paired results of inflows and outflows side-by-side for the same location-crop combinations. Following this, we look at the relationship between ratios of ancillary parameters and Hg species to assess the likelihood of mercury mobilization through the ancillary parameters, such as DOC or TSS. We also look at the values of Hg species and ancillary parameters for individual stations to identify correlations where possible. Finally, we present estimates of mercury exports given approximations of water application rates described in the previous section.

4.1 COMPARISON OF INFLOWS ACROSS STUDY LOCATIONS

Examination of the inflow data directly allows us to evaluate the source water conditions at different study locations. These box-plots are shown in Figure 4-1 through Figure 4-9 and summarized briefly below.

Total mercury: Inflow Hg concentrations ranged from 1-13 ng/l and were noticeably higher at the McCormick and Dixon-3 locations.

Methylmercury: Inflow MeHg concentrations ranged from non-detect to 0.4 ng/l, and were higher at the three McCormick fields sampled.

DOC: Inflow DOC concentrations are primarily in a narrow range of 1.5 − 3.5 mg/L with values that did not differ significantly across locations.

TSS: Inflow TSS concentrations were close to detection limit for the majority of the measurements, with some individual values ranging to 95 mg/l.

EC: Dixon sites 1, 2, and 3 show elevated EC with respect to the other sites which have values clustered around 150 µS/cm. This may be related to the relative position of the Dixon sites in the western Delta, with greater estuarine salt water influence.

DO: The inflow waters sampled appear to be fairly well oxygenated, with virtually all samples greater than 5 mg/l.

MeHg/Hg ratio: The majority of the samples fall within a range of 0.02 to 0.06, or 2 to 6% of the mercury as methylmercury.

Hg/DOC: The McCormick sites have elevated inflow Hg/DOC ratios with respect to the other sites

Hg/TSS: The McCormick corn sites have inflow Hg/TSS concentrations that are elevated with respect to the other sites (in excess of 1 µg/g), with the exception of the Dixon 3 site which has a single point.

Comparing across sites, it appears that the McMormick sites tend to have higher Hg and MeHg concentrations in inflows despite all other constituents generally being similar.

4.2 EVALUATION OF INFLOWS AND OUTFLOWS

A comparison of inflows and outflows by location allows for an evaluation of changes occurring in transport through the individual fields. The paired box-plots are shown in Figure 4-10 through Figure 4-19.

Total mercury: Outflow Hg concentrations are generally an order of magnitude elevated with respect to inflow Hg concentrations. Some of the highest concentrations are seen in the McCormick corn locations.

Methylmercury: Outflow MeHg concentrations are seen to generally be elevated with respect to inflow MeHg concentrations, with Staten Island Pasture sites exhibiting the greatest increases. One site, the McCormick 1 corn site shows no increase in MeHg concentrations.

DOC: Outflow DOC concentrations are always elevated with respect to inflow DOC concentrations, which is not surprising given the biomass being produced in the irrigated fields.

TSS: Outflow TSS concentrations are often significantly elevated with respect to inflow TSS concentrations (order or magnitude increase or more). This is consistent with observations of clearly cloudy waters as shown in the photographs in Chapter 2.

EC: EC values measured for the outflow at sites were slightly elevated but not to the extent they were elevated for TSS and DOC. As discussed in Chapter 3, an elevation of EC is to be expected because of evapotranspirative losses of water in the fields.

DO: DO levels were fairly high in the inflow and outflow, and no meaningful change is seen.

MeHg/Hg: Outflow MeHg/Hg ratios are higher than inflow MeHg/Hg ratios, suggesting greater methylation for one of the alfalfa and pasture sites, but the ratios do not increase for most sites. For the tomato and corn sites there are decreases in the ratio.

Hg/DOC: With the exception of increases at the McCormick corn sites, there was little change in the ratio at the other locations.

Hg/TSS: Sites generally show increased Hg/TSS outflow concentration with respect to inflow concentration, with the exceptions of Staten Island 2 Alfalfa and Dixon 3 Tomato.

4.3 EVALUATIONS OF INFLOWS AND DRAINS

The drains integrate the effects of outflows from multiple fields, so they cannot easily be related to inflows or crops at a single location. However, the comparisons with inflow values are indicative of the net effect of different fields, or of agricultural drainage at a general location, not necessarily tied to a crop type, as is possible with the set of plots shown in the previous section. The paired box-plots are shown in Figure 4-20 through Figure 4-28.

Total mercury: Drain Hg concentrations are elevated with respect to inflow Hg concentrations, at all locations.

Methylmercury: Drain MeHg concentrations elevated, oftentimes near an order of magnitude, to inflow MeHg concentrations at all locations.

DOC: DOC drain concentrations are generally elevated with respect to DOC inflow concentrations, and consistent with the pattern seen for the outflow stations. The Staten Island sites exhibit the greatest increase.

TSS: Drain TSS concentrations are always elevated with respect to inflow TSS concentrations. Some values in the drains were in excess of 100 mg/l.

EC: Drain EC is elevated with respect to inflow EC, with the Dixon and Staten Island sites exhibiting the largest increase. The EC increase is greater than seen for the outflow sites.

DO: DO drain concentrations are marginally than DO inflow concentrations, although the waters are fairly well oxygenated with the exception of one sample at the Dixon 2 site.

MeHg/Hg: Drain MeHg/Hg concentration ratios are typically larger than or similar to inflow MeHg/Hg concentration ratios, although the McCormick 1 Corn exhibits a notable decrease.

Hg/DOC: Across locations, the drain values seem to generally track the inflow values. Of the locations with paired measurements, about half show increases and half show decreases.

Hg/TSS: There are no clear patterns in this ratio, with some sites showing substantial increases (McCormick 1 corn), while others show large decreases (Dixon 3 tomato).

4.4 EVALUATION OF MERCURY RATIOS WITH ANCILLARY PARAMETER RATIOS

Examination of paired ratios of mercury species and ancillary parameters provide insight into the possible causes of the changes. Thus elevated DOC can be a mechanism mobilization of methylmercury and possibly mercury; TSS can be associated with total mercury mobilization; and EC ratios are indicative of the concentration increase that can be attributed to evaporation. For the design of the present study, ratios across three site types are meaningful: drain/inflow; drain/outflow; and outflow/inflow. Both Hg and MeHg are explored through these pairings. For most plots discussed below, the relationships are interpreted visually. Correlations are reported only where they are statistically significant.

4.4.1HG TRANSPORT

Hg ratio versus DOC ratio (Figure 4-29 through Figure 4-31): There is a poor relationship between DOC and Hg ratios across all three site-type pairings. The best relationship is between drains and outflow suggesting similar drain processes affecting both constituents. However, the comparisons that consider field transport (In:drain, In:out) are more scattered suggest different mechanisms driving transport and production or removal of Hg and DOC at the field scale.

Hg ratio versus EC ratio (Figure 4-32 through Figure 4-34): These relationships are similar to those for DOC, with similar overall trends though different magnitudes. When the outflow and inflow pairs are compared, Hg ratios are consistently higher indicating that a process other than evapoconcentration is associated with the change. In contrast, when the drain:outflow ratio is considered, the Hg values are well below the corresponding EC ratio. Thus indicates the Hg concentrations are lower than what might be expected by further concentration in the drains, and is likely a result of settling or other removal process. The drain:inflow pairing suggests a similar magnitude of change. In other words, if all we had was data on the inflows and the drains, the Hg levels would be of the same order of magnitude as predicted by evapoconcentration.

Hg ratio versus TSS ratio (Figure 4-35 through Figure 4-37): The outflow:inflow pairing suggest a weak positive relationship, indicating that higher TSS values correspond to higher total Hg, although there are some points that are well above the 1:1 line. These high points imply that the TSS alone does not explain the elevated concentrations, and may be associated with particulate concentrations that are higher than other locations. When the drain:outflow values are plotted, the TSS ratios and the Hg ratios are typically below 1, indicating settling of Hg and TSS in the drains following discharge from the outflows.

4.4.2MEHG

MeHg ratio versus DOC ratio (Figure 4-38 through Figure 4-40): MeHg ratios appear to be related with DOC ratios, strongly indicating that MeHg and DOC are transported together. Thus, in the outflow:inflow pairings, the MeHg and DOC ratios track each other well, and high MeHg ratios correspond to high DOC ratios. The relationship is somewhat weaker for the other pairings, but there is generally a positive relationship. In the drain:outflow pairing, the ratios are from approximately 0.2-2, with most sites showing an increase in DOC, and a similar range for MeHg ratios. Thus, drain concentrations continue to be elevated in MeHg, unlike for total Hg, where there is a decrease in the drains.

MeHg ratio versus EC ratio (Figure 4-41 through Figure 4-43): MeHg ratios are much higher than EC ratios (outflow:inflow pair), clearly indicating that the concentrations cannot be explained by evapoconcentration. When the pairing with the drains are considered, however, especially drain:outflow, the MeHg ratios are of the same order of magnitude for several of the stations, indicating that when the drains are considered, evapoconcentration can explain some of the elevated MeHg. This is not true for all locations, indeed there are some stations associated with alfalfa that are much higher than would be predicted by evapoconcentration alone (well above the 1:1 line). Overall, this set of plots suggest that MeHg values are strongly elevated in the outflows, but that there are loss mechanisms in the drains, such that the net effect is of concentrations that can substantially be explained by water loss processes.

MeHg ratio versus TSS ratio (Figure 4-44 through Figure 4-46): In all the data pairings, instances the MeHg ratio is much higher that the TSS ratio, suggesting that TSS is not a strong enabler of MeHg elevation. This may be compared to the Hg-TSS plots, where the Hg ratios are more similar to the TSS ratios suggesting a stronger association.

4.5 RELATIONSHIPS BETWEEN MERCURY AND ANCILLARY PARAMETERS FOR SPECIFIC LOCATIONS AND CROPS

In addition to the plots above that combine data across multiple locations, we also looked at the effect of location, crop, site type separately in a series of plots that are summarized in Appendix B. In these plots, we evaluate a single crop at a single location, further classify by station type (inflow, outflow, or drain), and identify correlations where between Hg or MeHg and TSS, EC, and DOC (if adequate data are available). The following general findings are noted:

- Total Hg and MeHg are generally both correlated positively with DOC across different station types, with only a few exceptions.

- Total Hg and TSS relationships are generally positive.
- EC levels are weak predictor of with Hg or MeHg.

Although this method of evaluating data leaves us with very few points in each category, it is helpful in that it a direct evaluation of relationships between basic water quality parameters and Hg species, without the confounding effects of site or crop. It is envisioned that the plots presented in Appendix B will provide general direction for additional data collection to quantify processes at a finer geographic and crop resolution.

4.6 ESTIMATED LOADS OF MERCURY AND METHYLMERCURY

A key objective of this work was the estimation of loads from irrigated agriculture. In the absence of water application rates at the different fields, we have approximated loads assuming the water application rates as described in Section 3.5. Because we assume two alternative rates of runoff and two alternative rates of percolation, four load calculations are possible using each set of inflow and outflow concentrations. Here we present the results for the lower runoff rate and the higher runoff rate, the effect of the percolation rate being incorporated in the box plots. In each case we show the inflow and outflow loads (1 plot) and the net loads (1 plot). Given two rates of runoff (10 and 25%) and two constituents (total Hg and MeHg), we end up with a set of 8 plots shown in Figure 4-47 through Figure 4-54. As expected the inflow loads are higher when we assume a higher runoff percent. However, a key finding from this exercise is that the net loads for most of the fields (except McCormick 1 tomato) is negative for total mercury, i.e., there is no net export when the runoff rate is 10%. The loads are less negative and positive for two fields (Dixon 3 tomato and McCormick 1 tomato) when the runoff rate is higher (25%, Figure 4-50). The median MeHg net load is, similar to the total Hg load, negative for all field when the runoff rate is 10% (Figure 4-52). With the higher runoff rate, the MeHg net load is positive for two fields (Staten Island 1 and 2 pasture), and negative for all others.

The load calculation exercise highlights the importance of the assumed water application rates. Because the outflow concentrations are higher than inflows for virtually all sample events, the net loads can be positive when the outflow volumes are proportionally higher. Thus, if the outflow concentrations were 10 times higher than inflow concentrations, but the outflow volumes are only a tenth of the inflow volumes, the net load would still be zero.

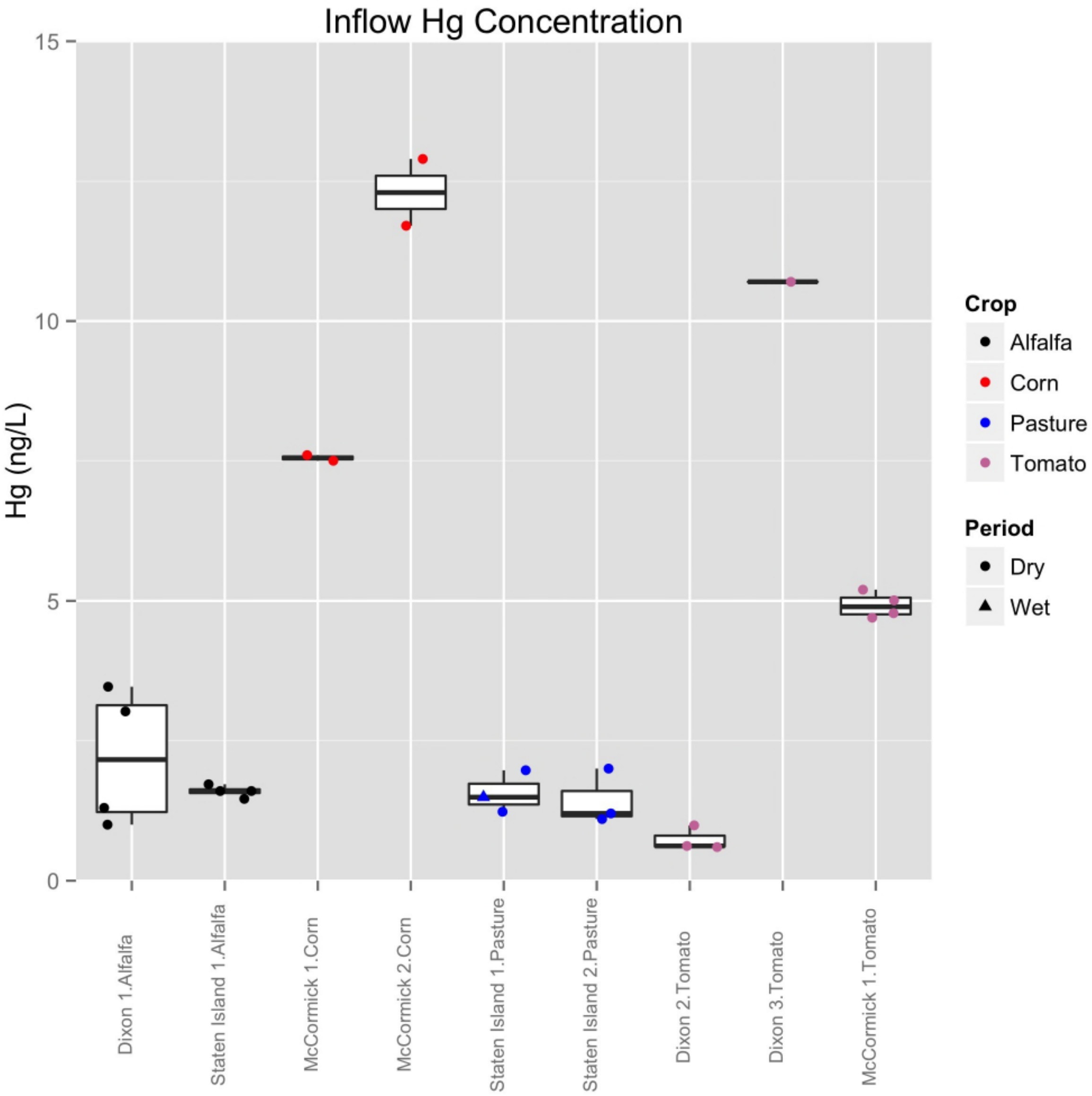


Figure 4-1 Inflow total Hg concentrations

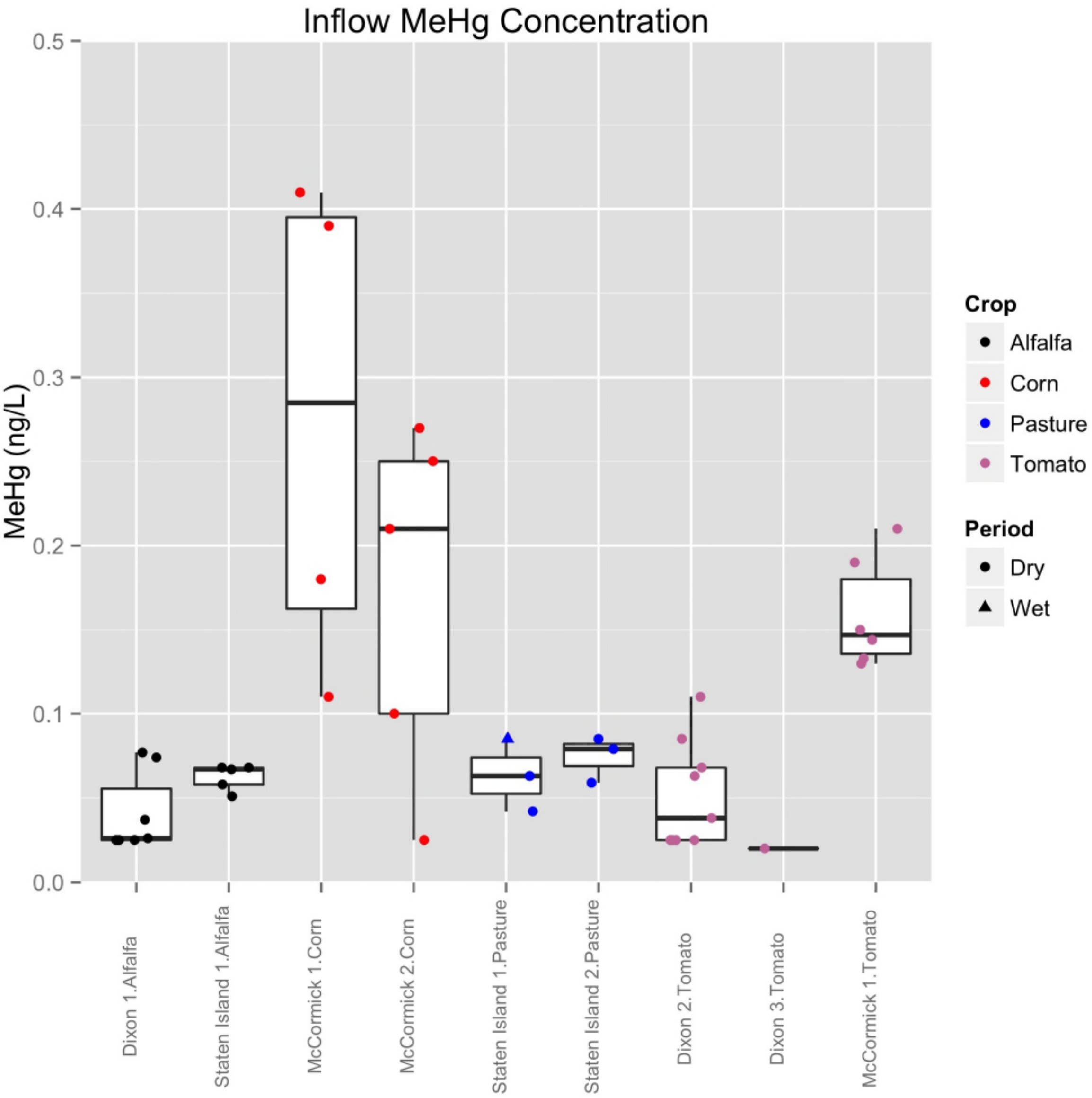


Figure 4-2 Inflow MeHg concentrations

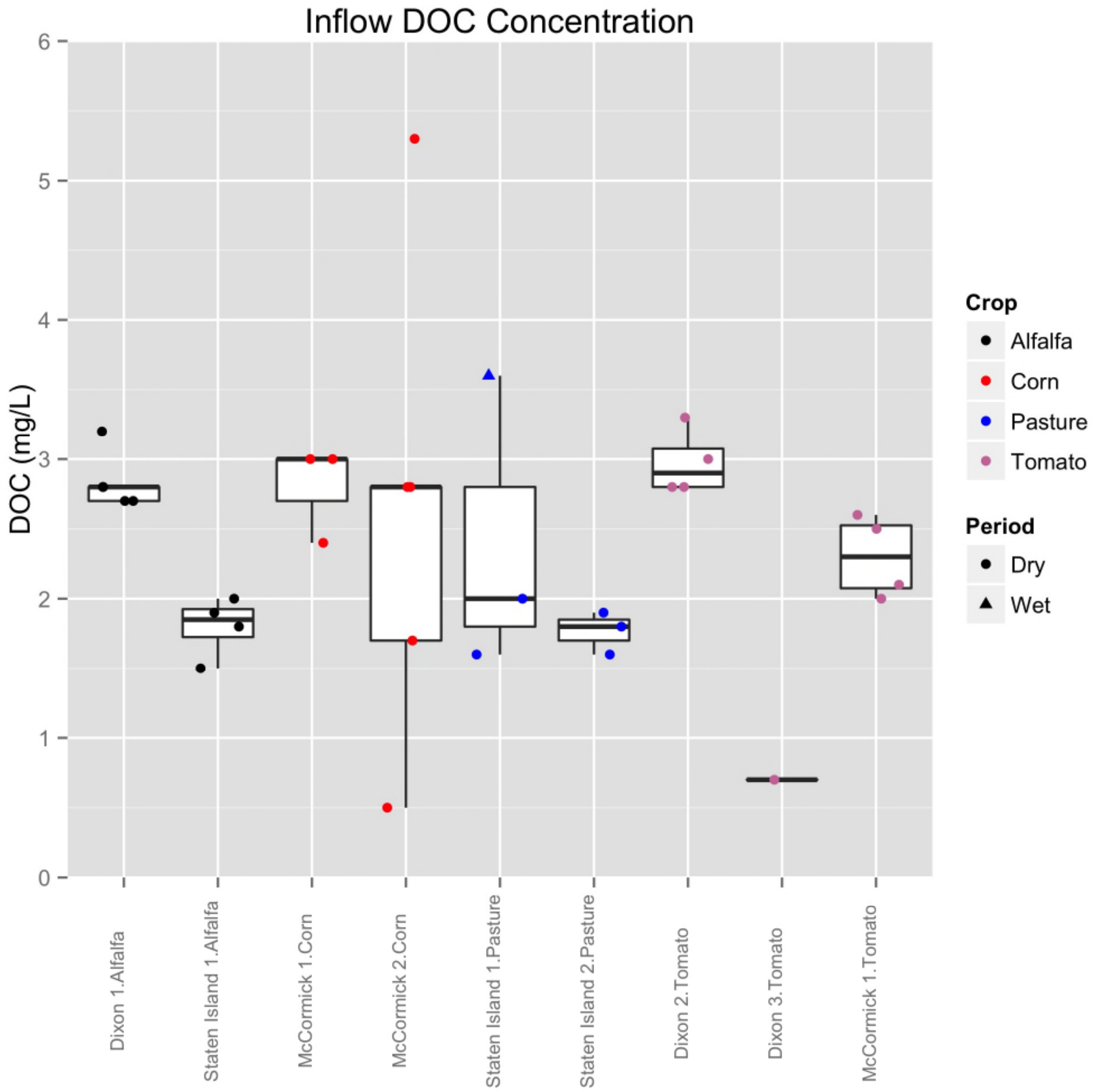


Figure 4-3 Inflow DOC concentrations.

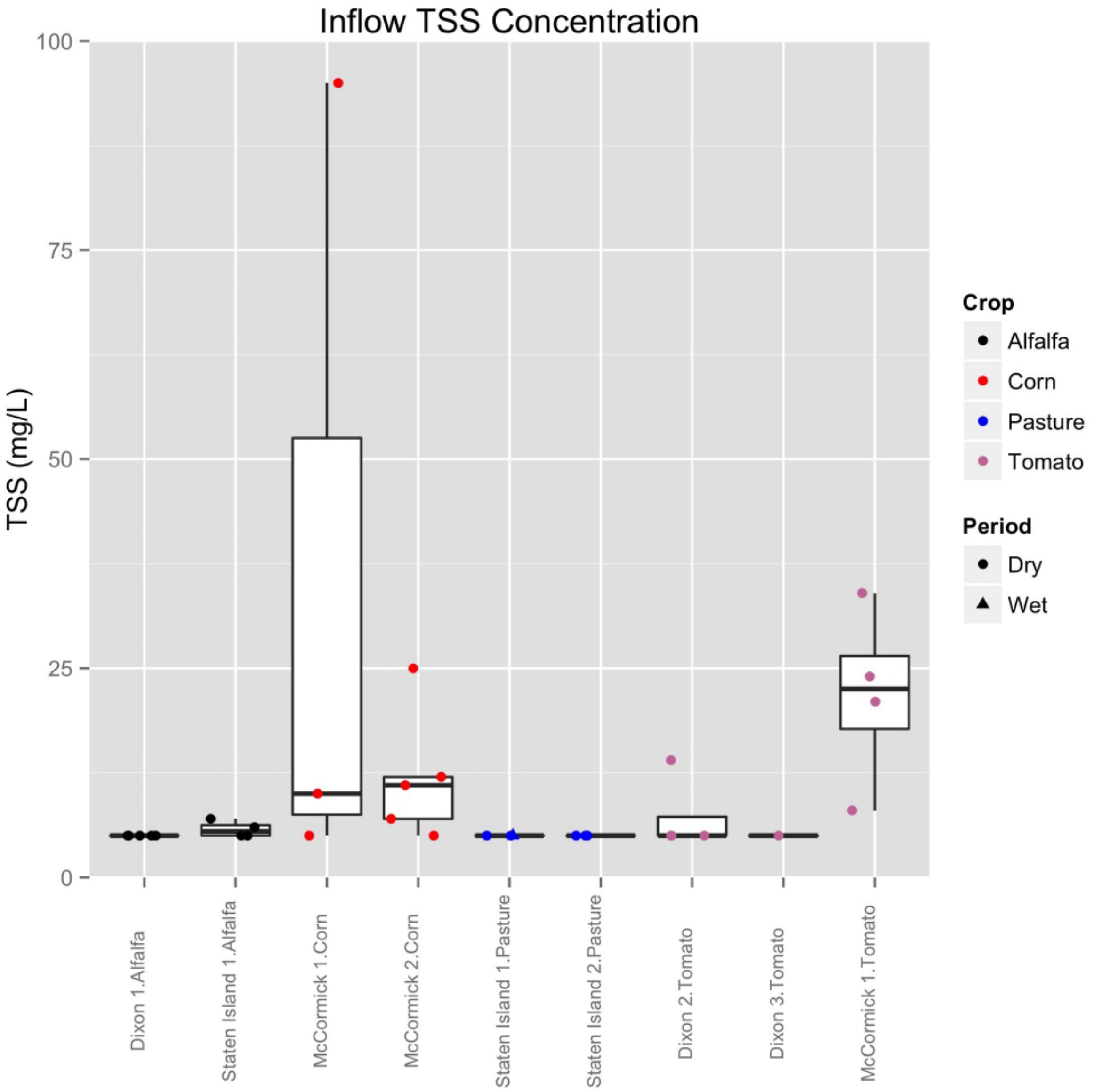


Figure 4-4 Inflow TSS concentrations

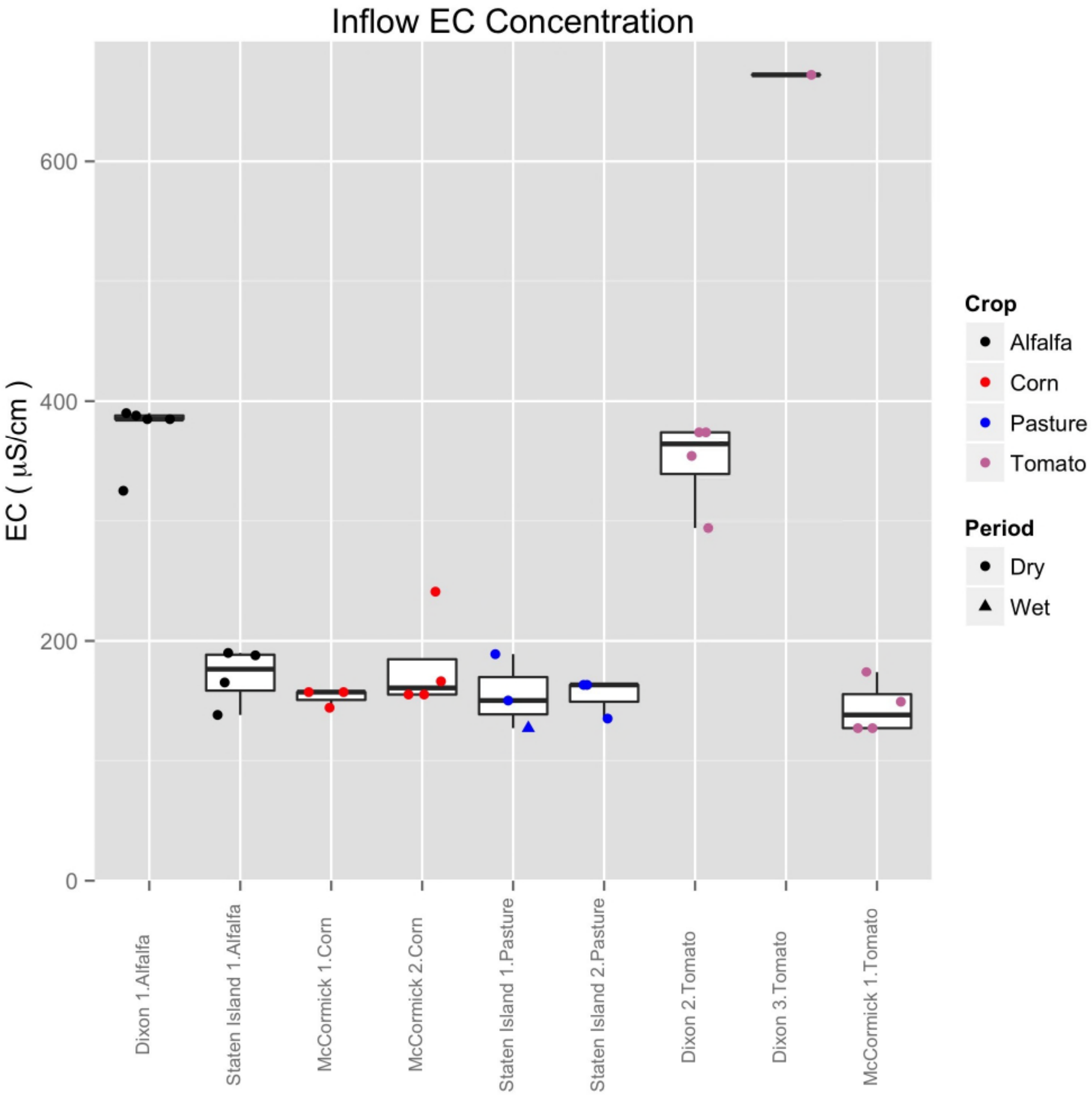


Figure 4-5 Inflow EC concentrations

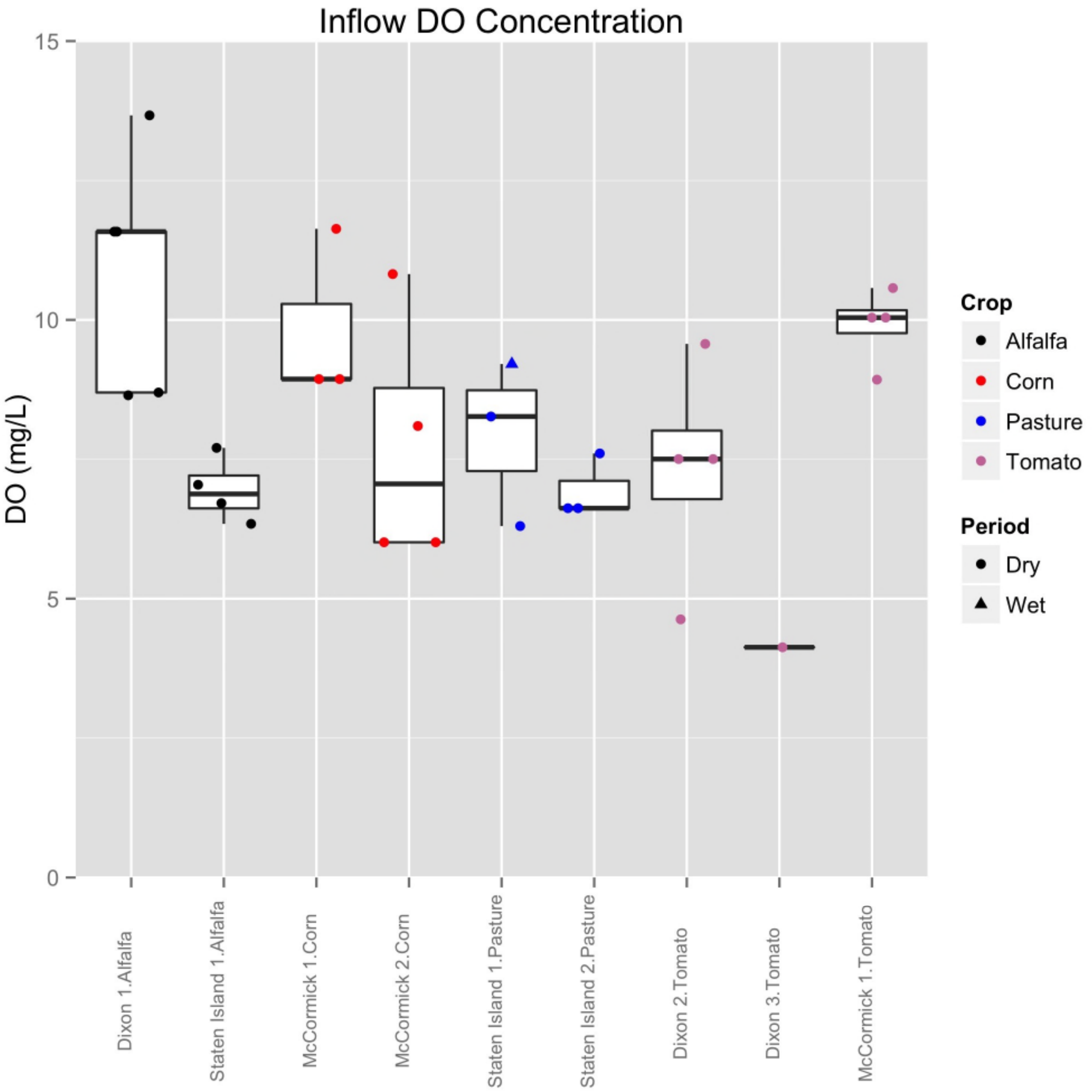


Figure 4-6 Inflow DO concentrations

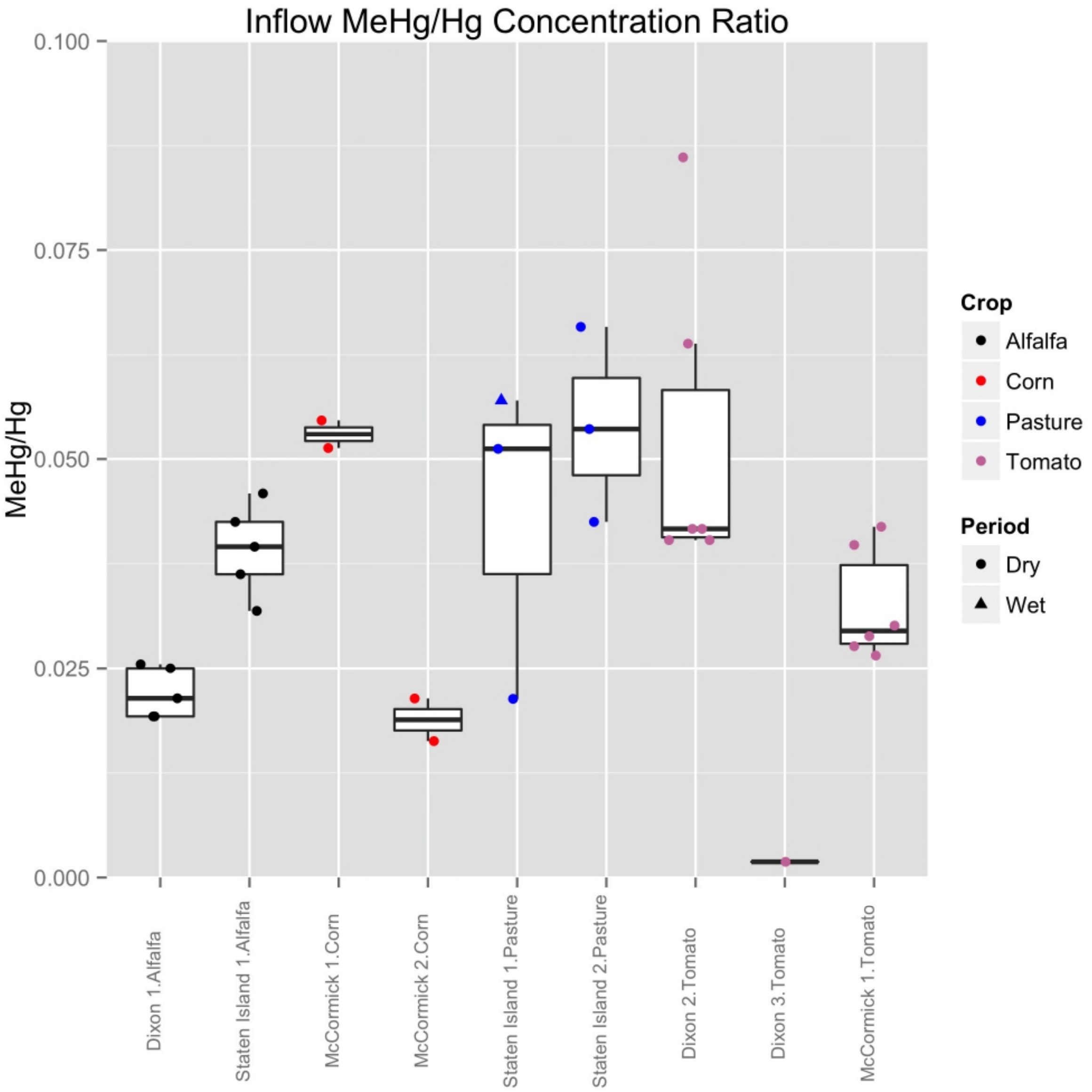


Figure 4-7 Ratio of MeHg to Hg concentrations

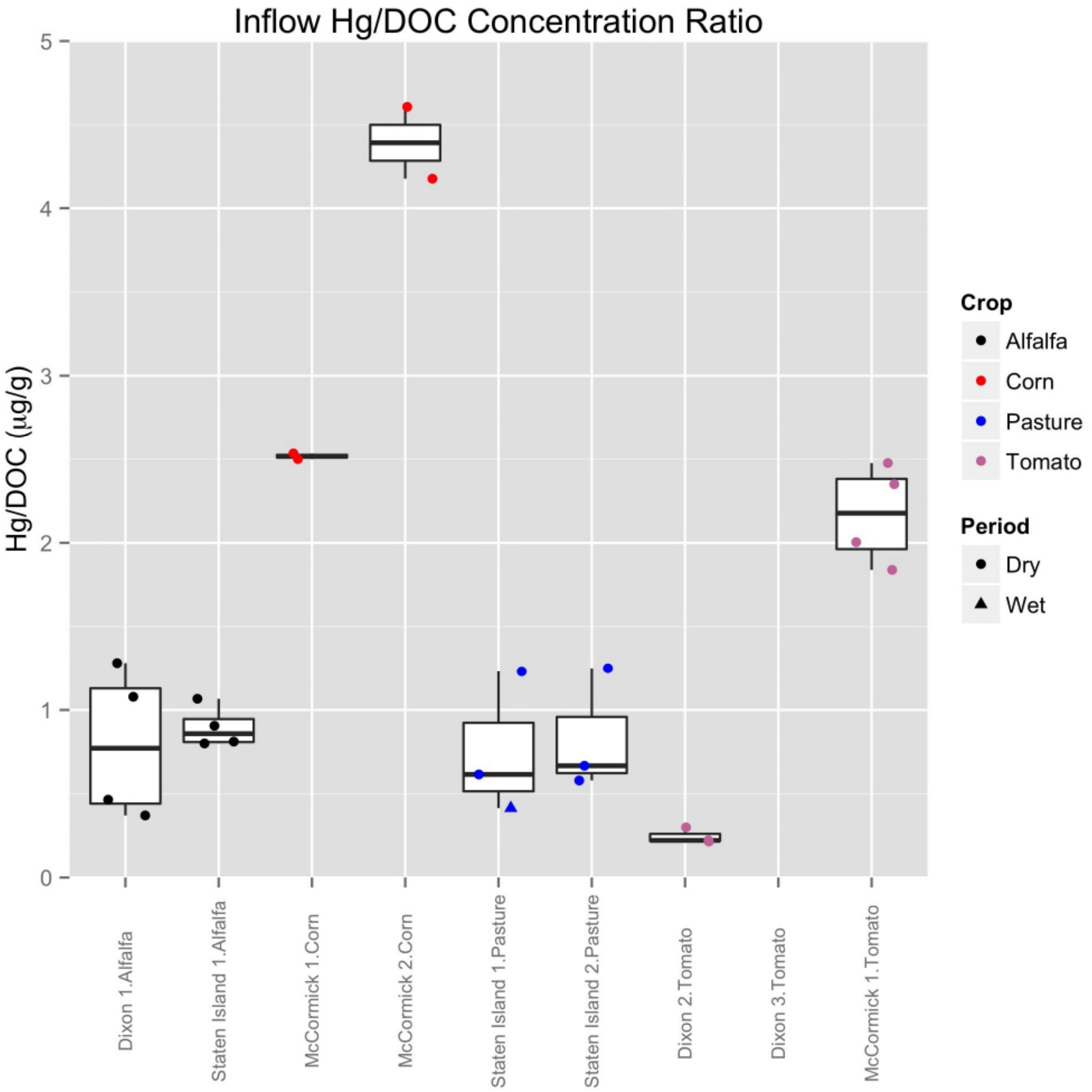


Figure 4-8 Ratio of Hg to DOC concentrations

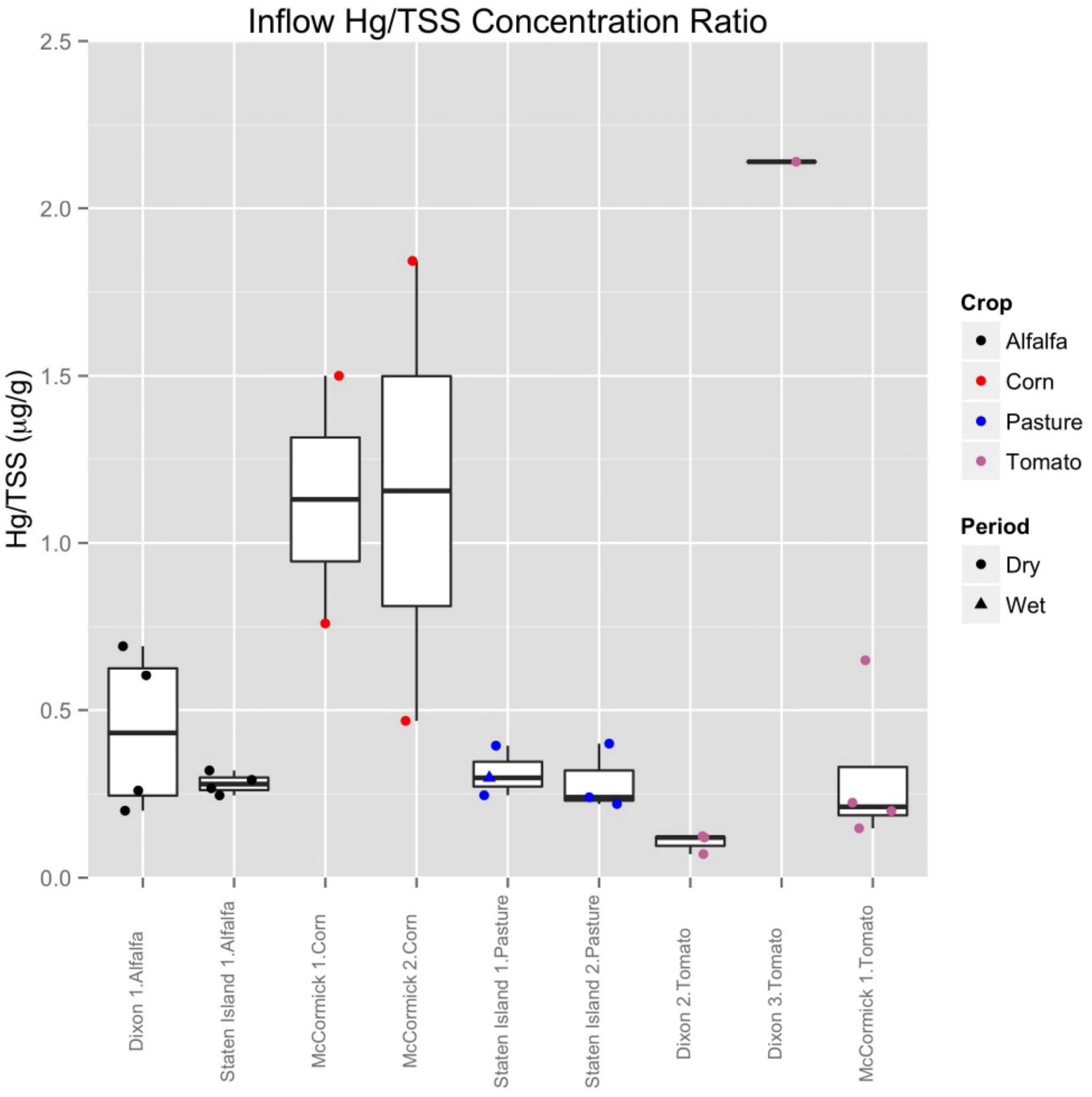


Figure 4-9 Ratio of Hg to TSS concentrations

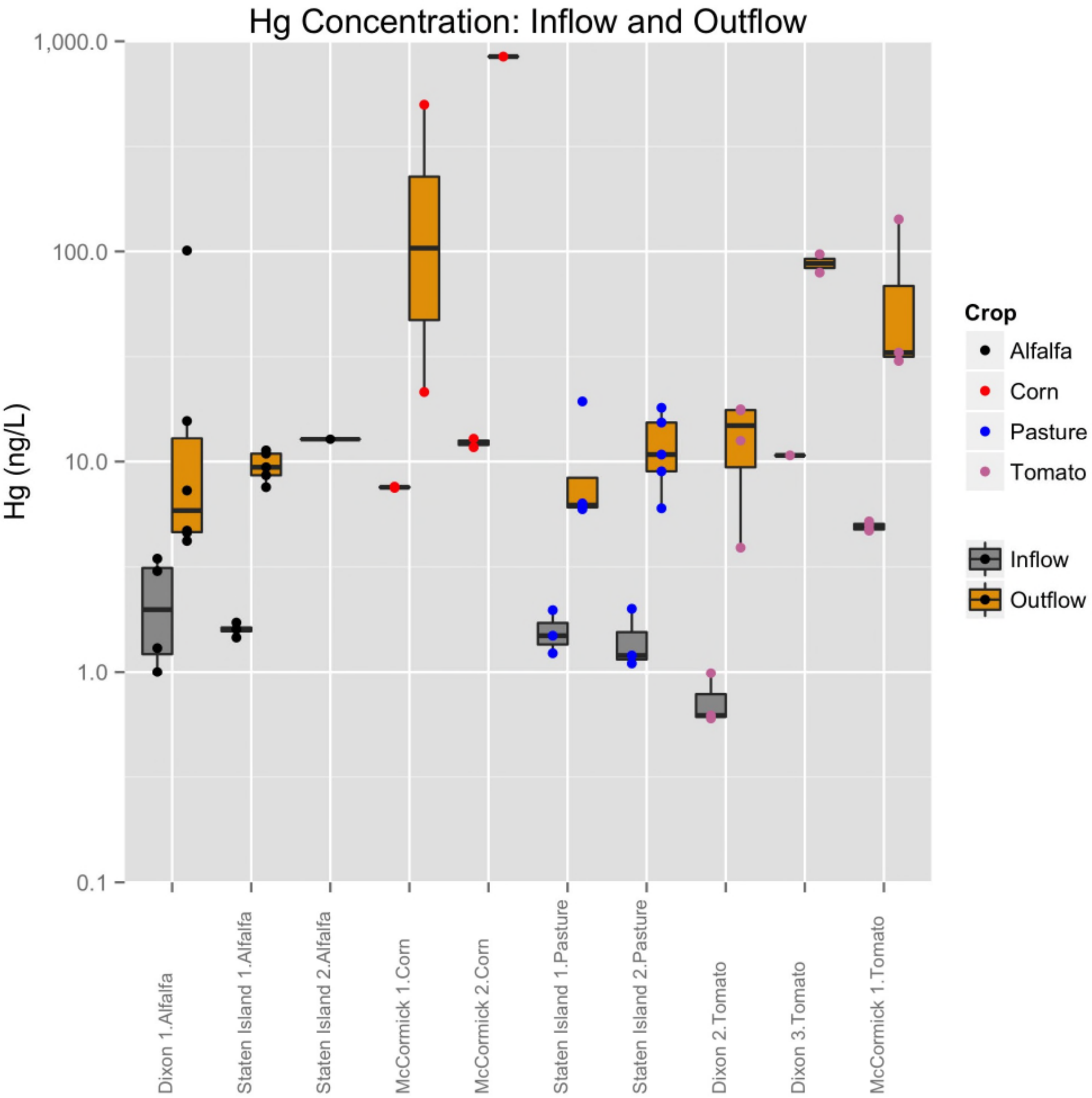


Figure 4-10 Comparison of inflows and outflows: Hg

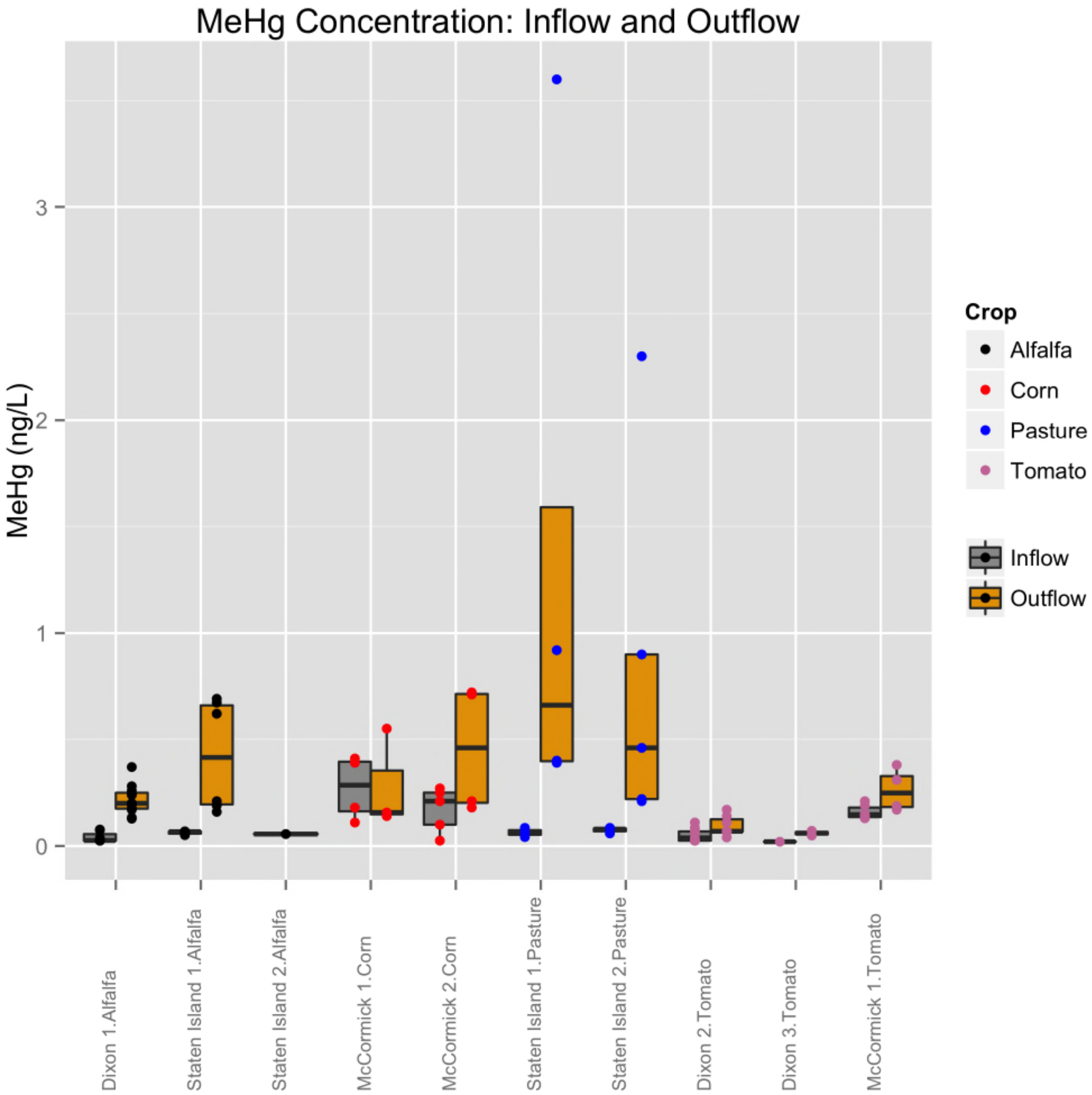


Figure 4-11 Comparison of inflows and outflows: MeHg

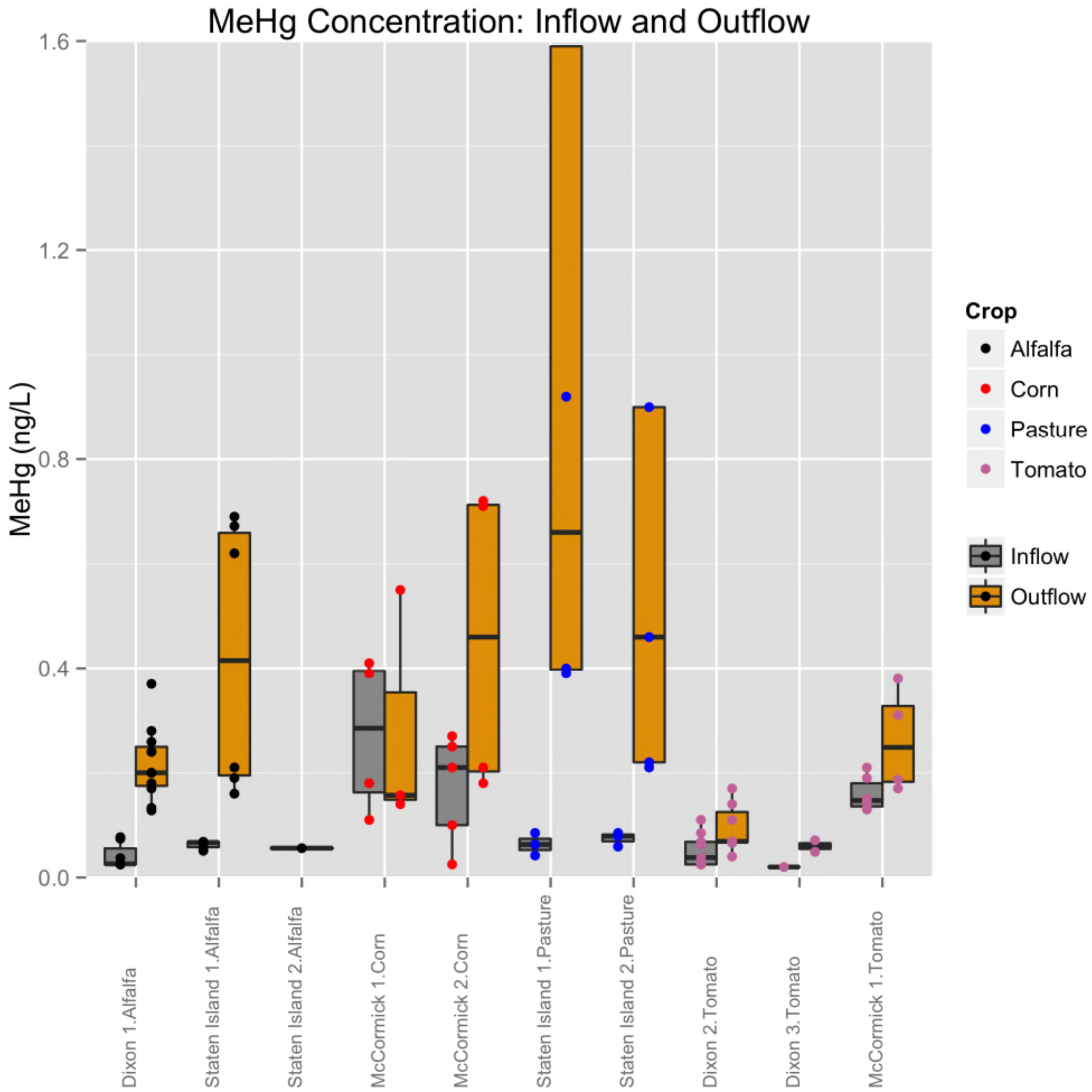


Figure 4-12 Comparison of inflows and outflows:MeHg (zoomed-in scale from previous plot)

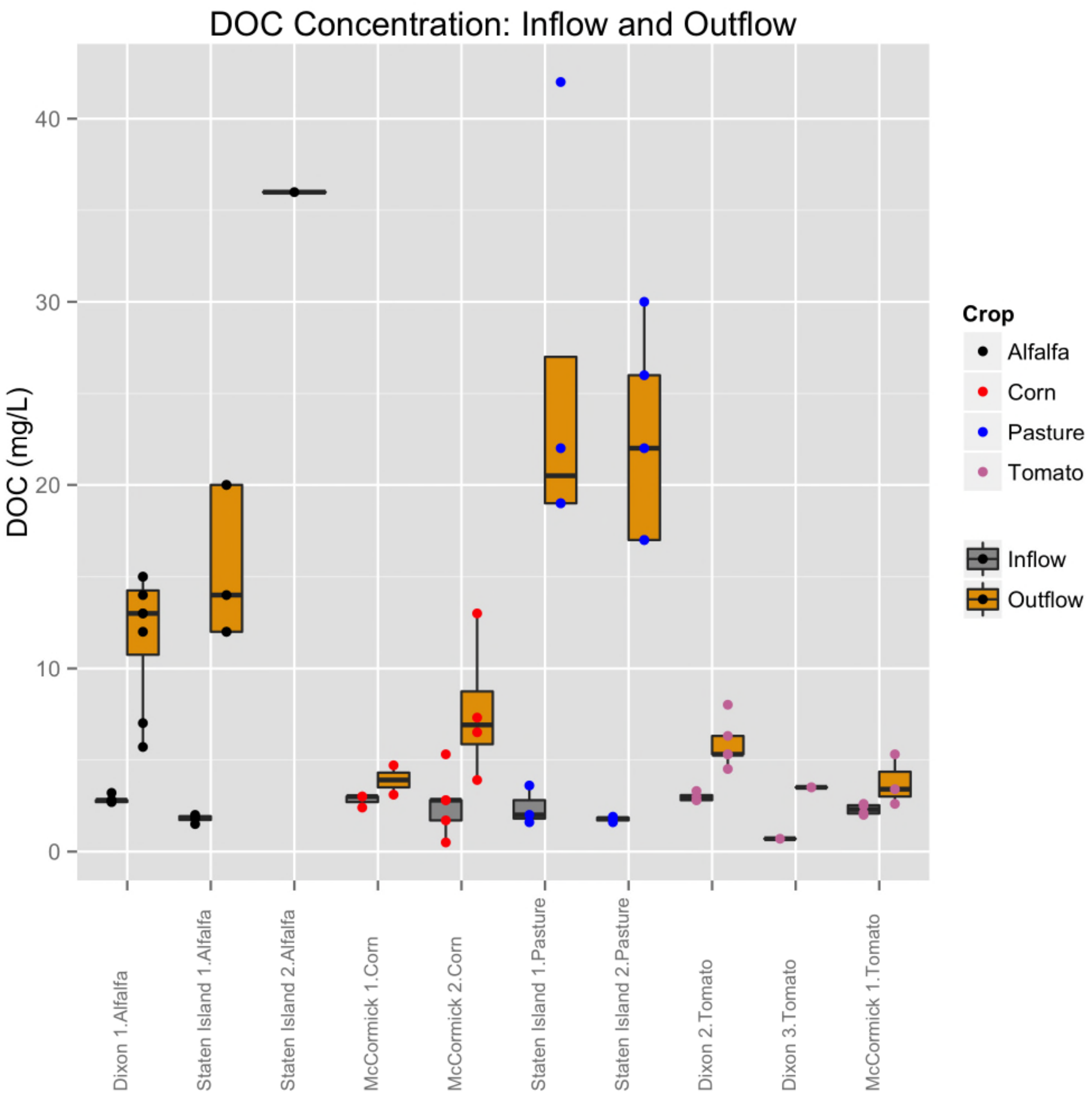


Figure 4-13 Comparison of inflows and outflows: DOC

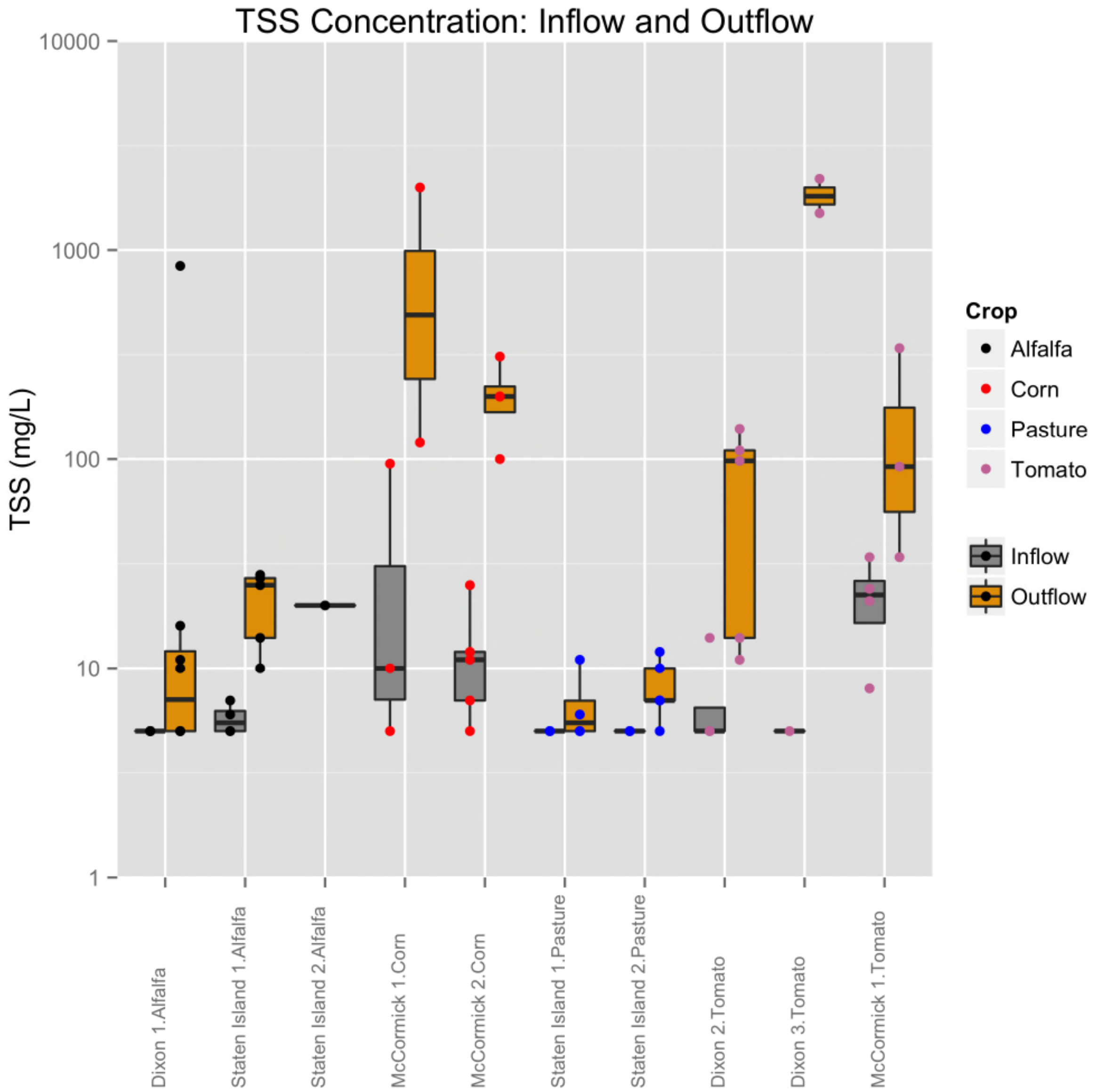


Figure 4-14 Comparison of inflows and outflows: TSS

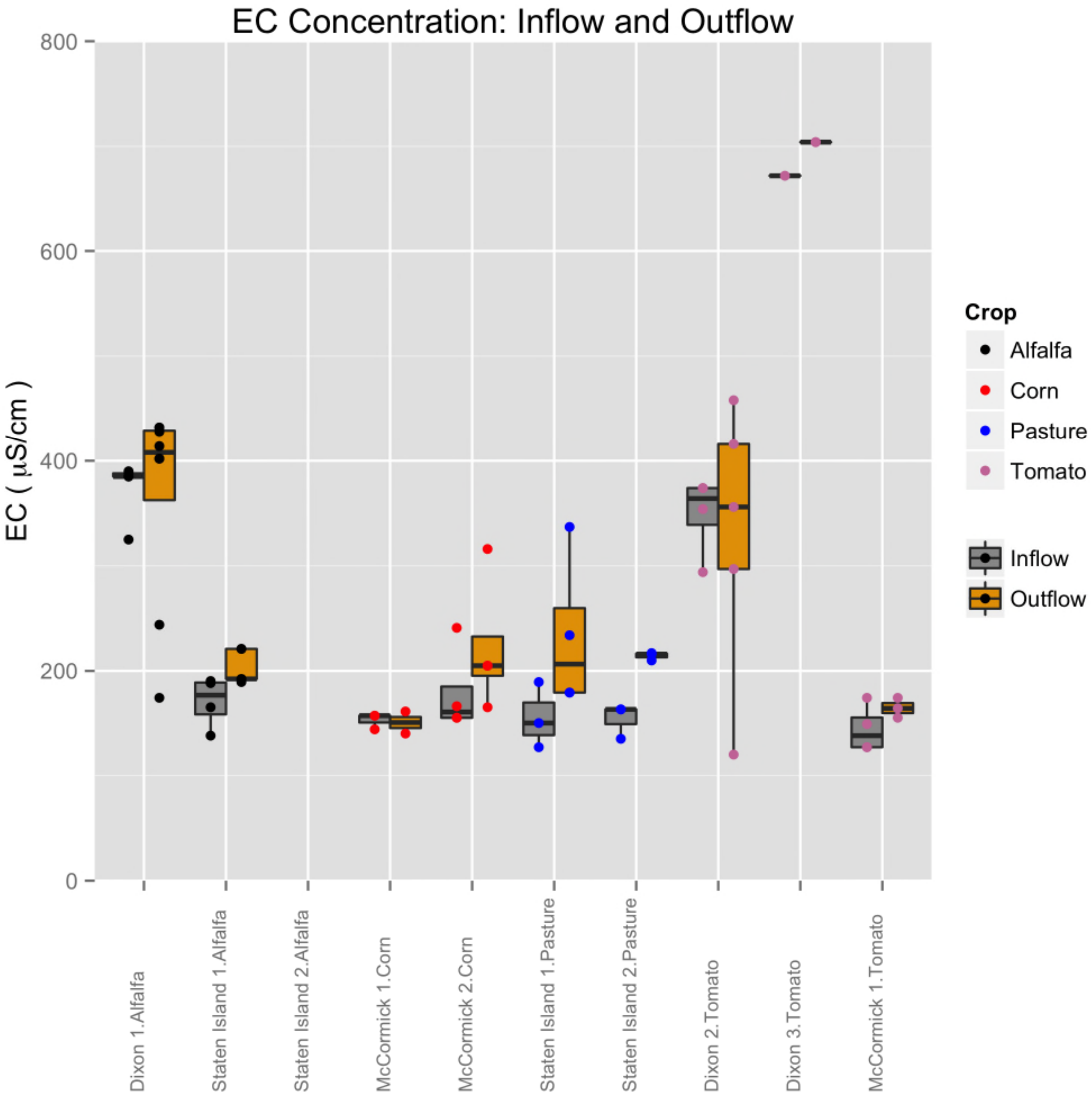


Figure 4-15 Comparison of inflows and outflows: EC

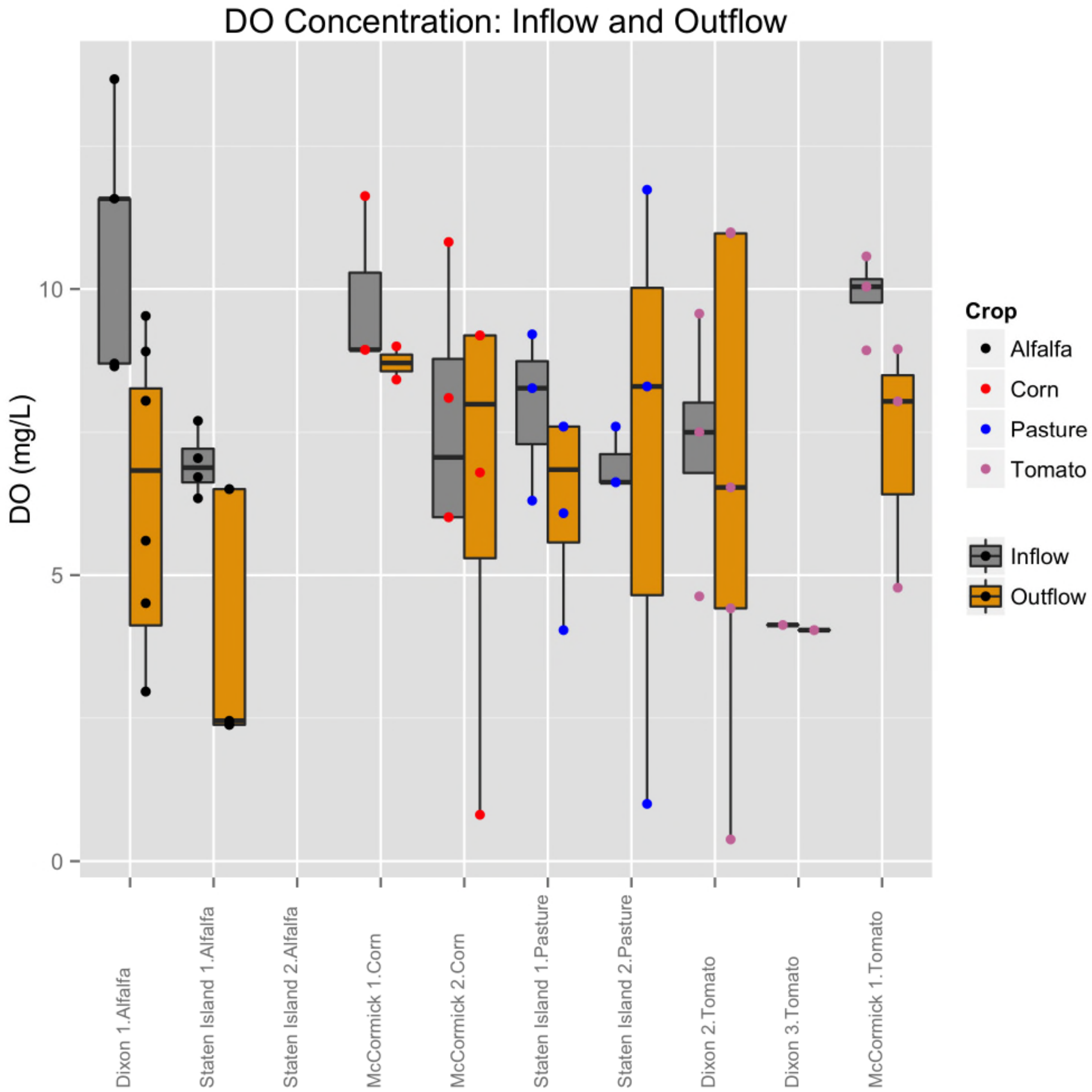


Figure 4-16 Comparison of inflows and outflows: DO

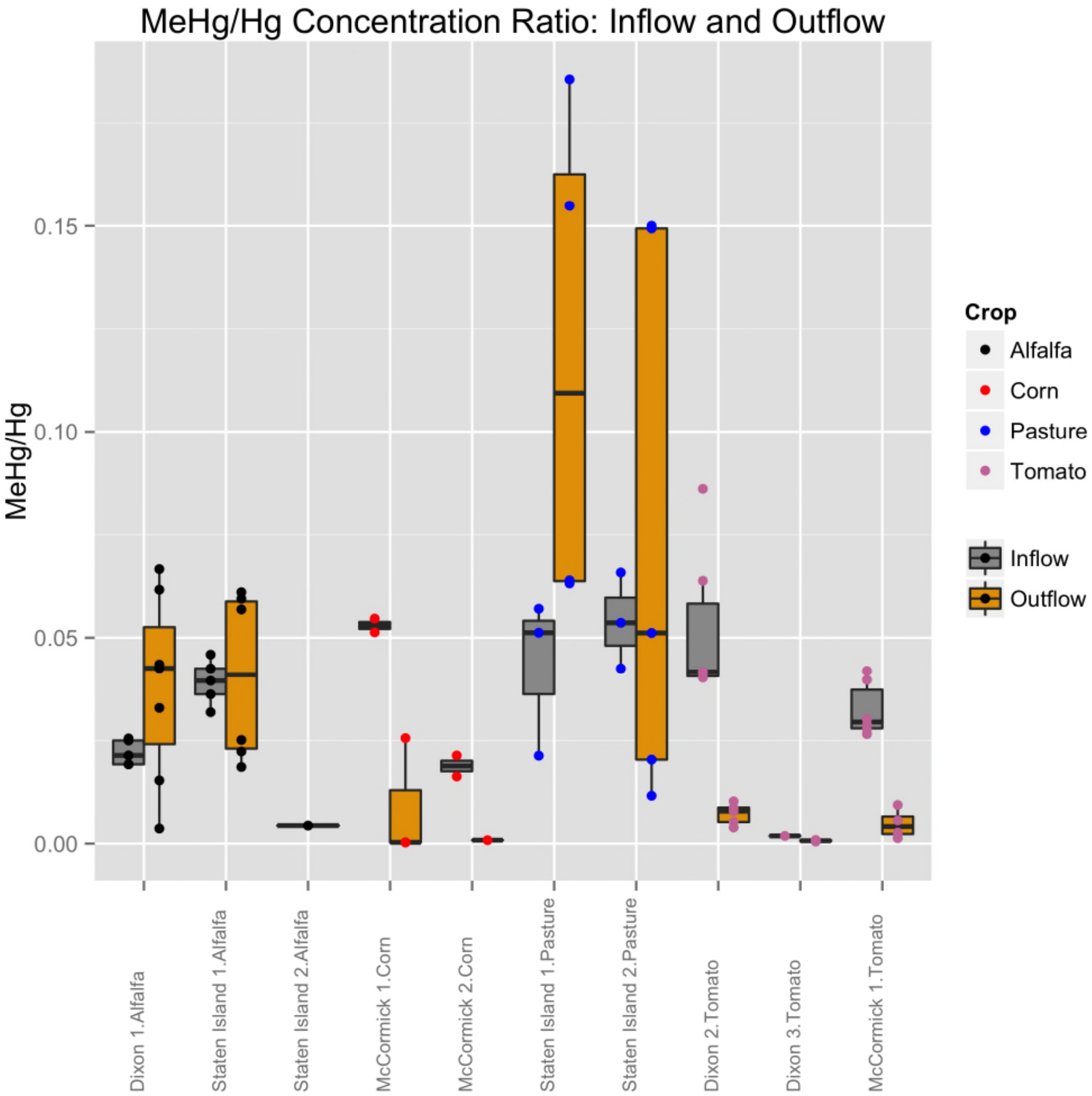


Figure 4-17 Comparison of inflows and outflows: MeHg/Hg

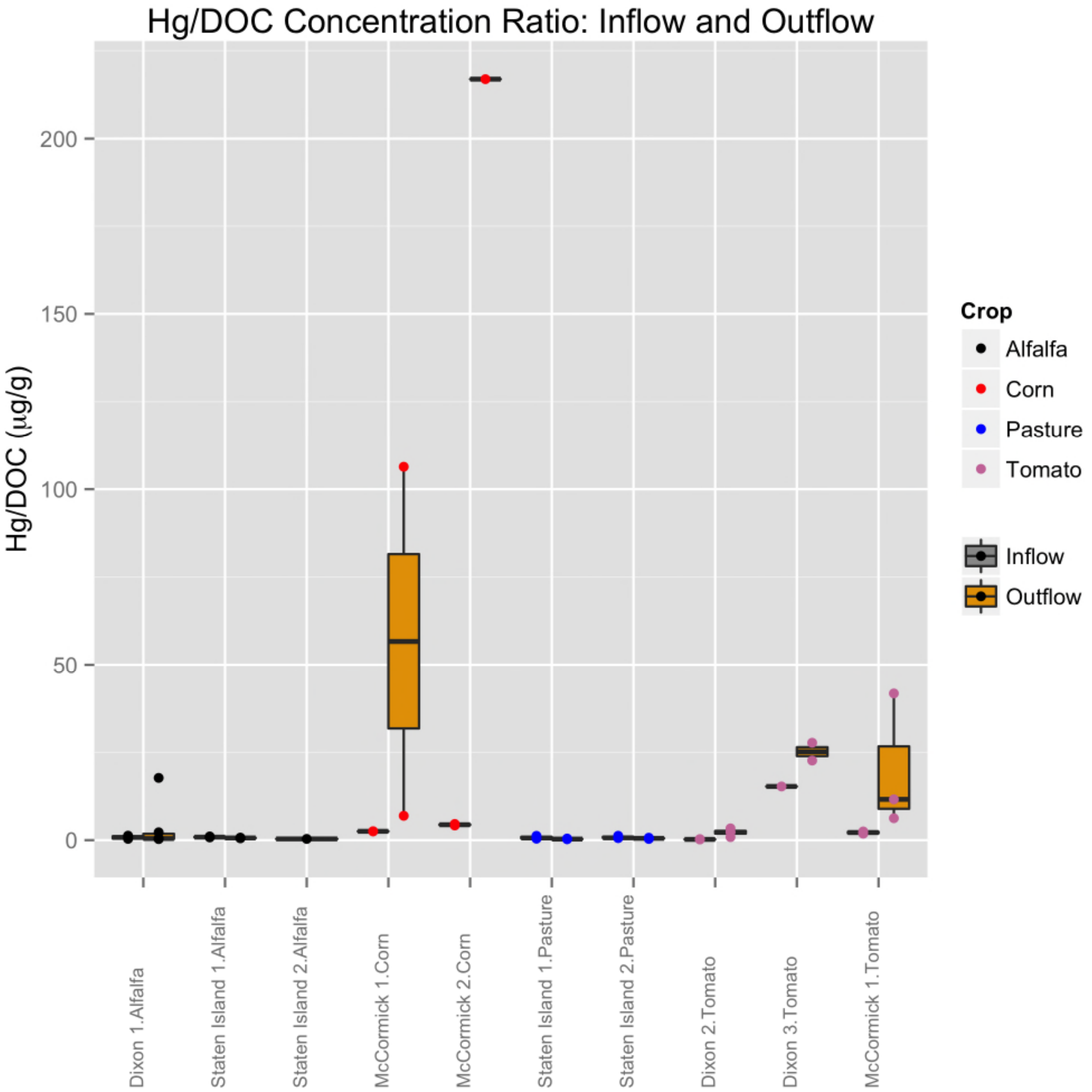


Figure 4-18 Comparison of inflows and outflows: Hg/DOC

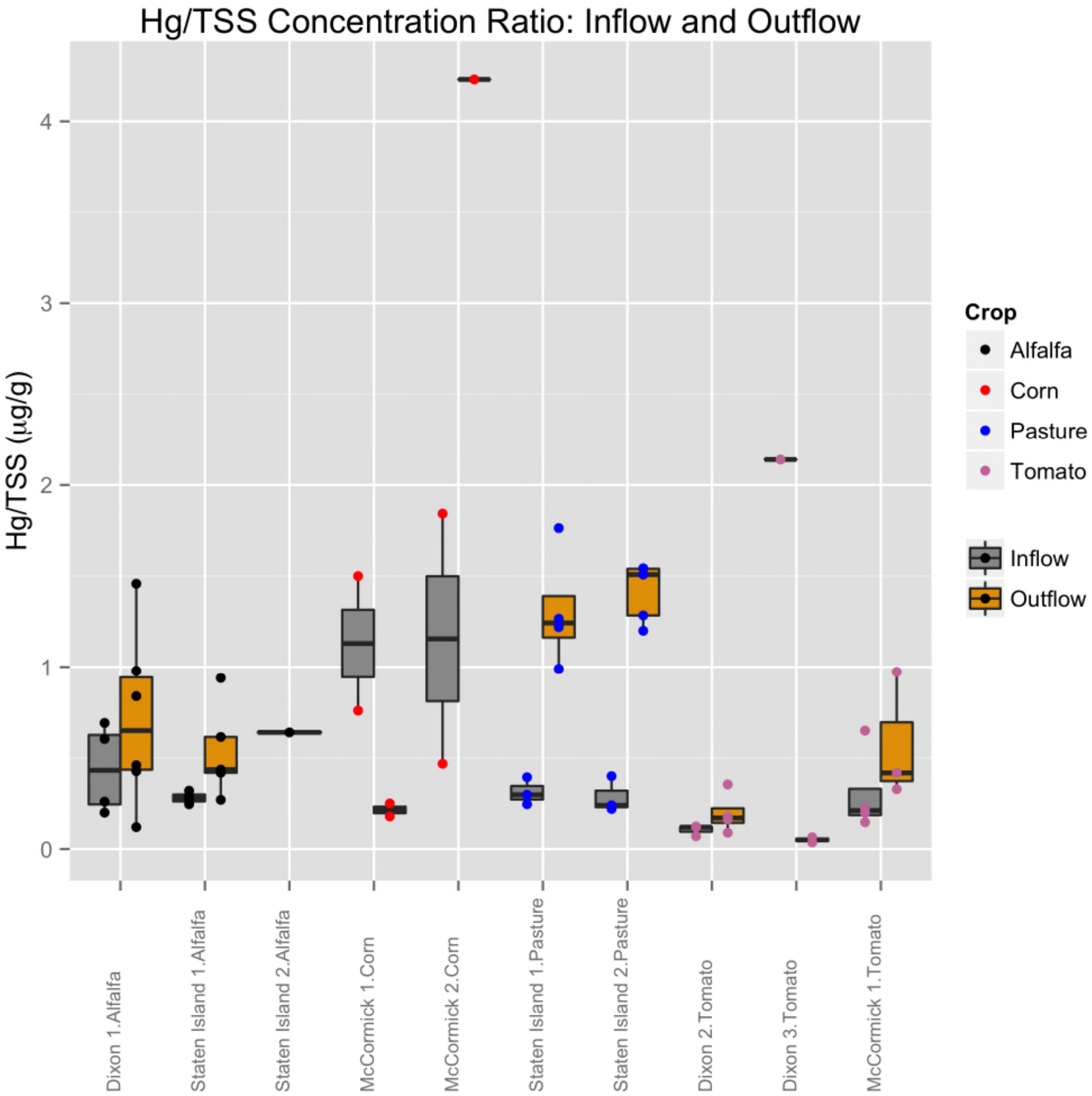


Figure 4-19 Comparison of inflows and outflows: Hg/TSS

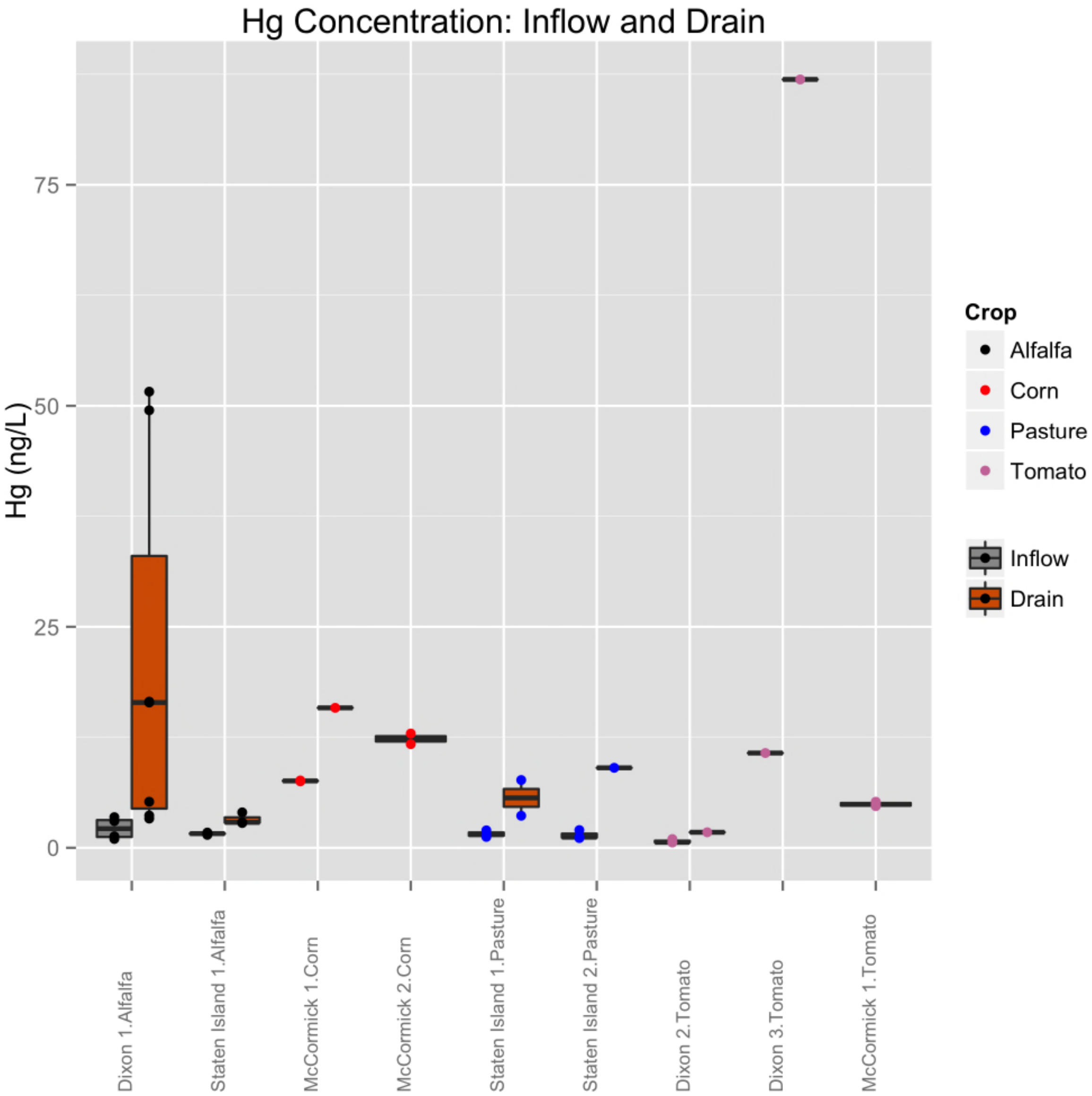


Figure 4-20 Comparison of inflows and drains: Hg

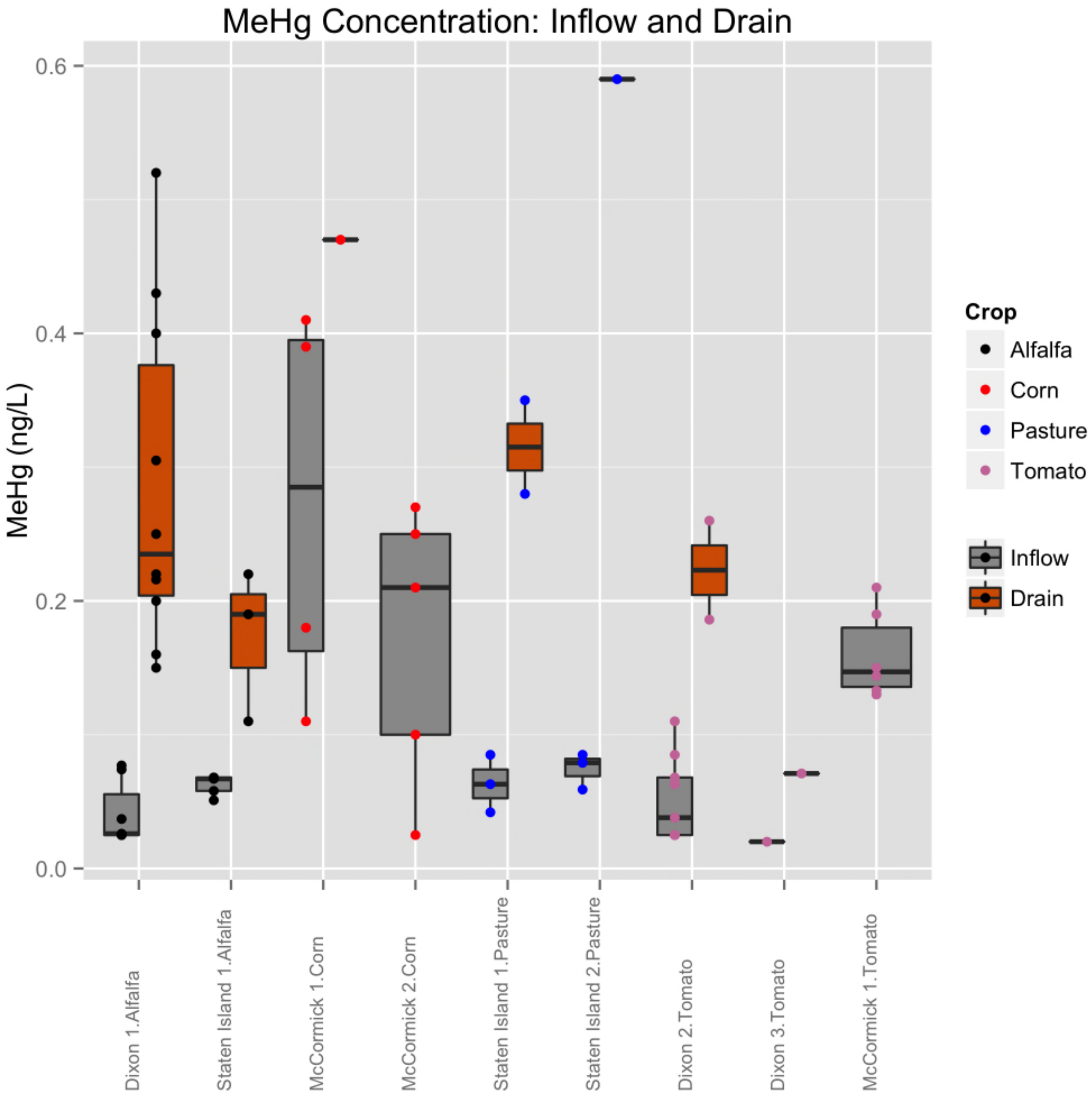


Figure 4-21 Comparison of inflows and drains: MeHg

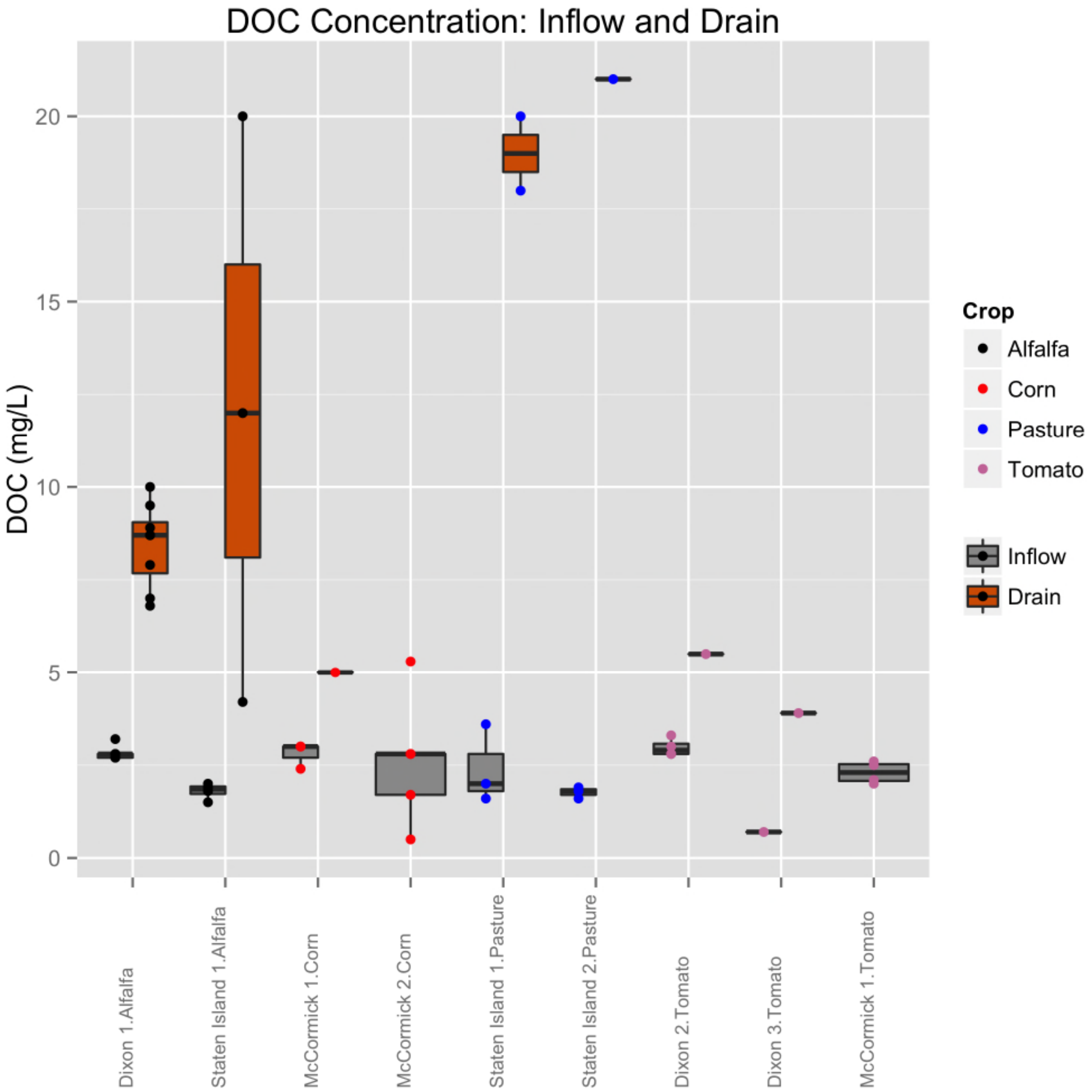


Figure 4-22 Comparison of inflows and drains: DOC

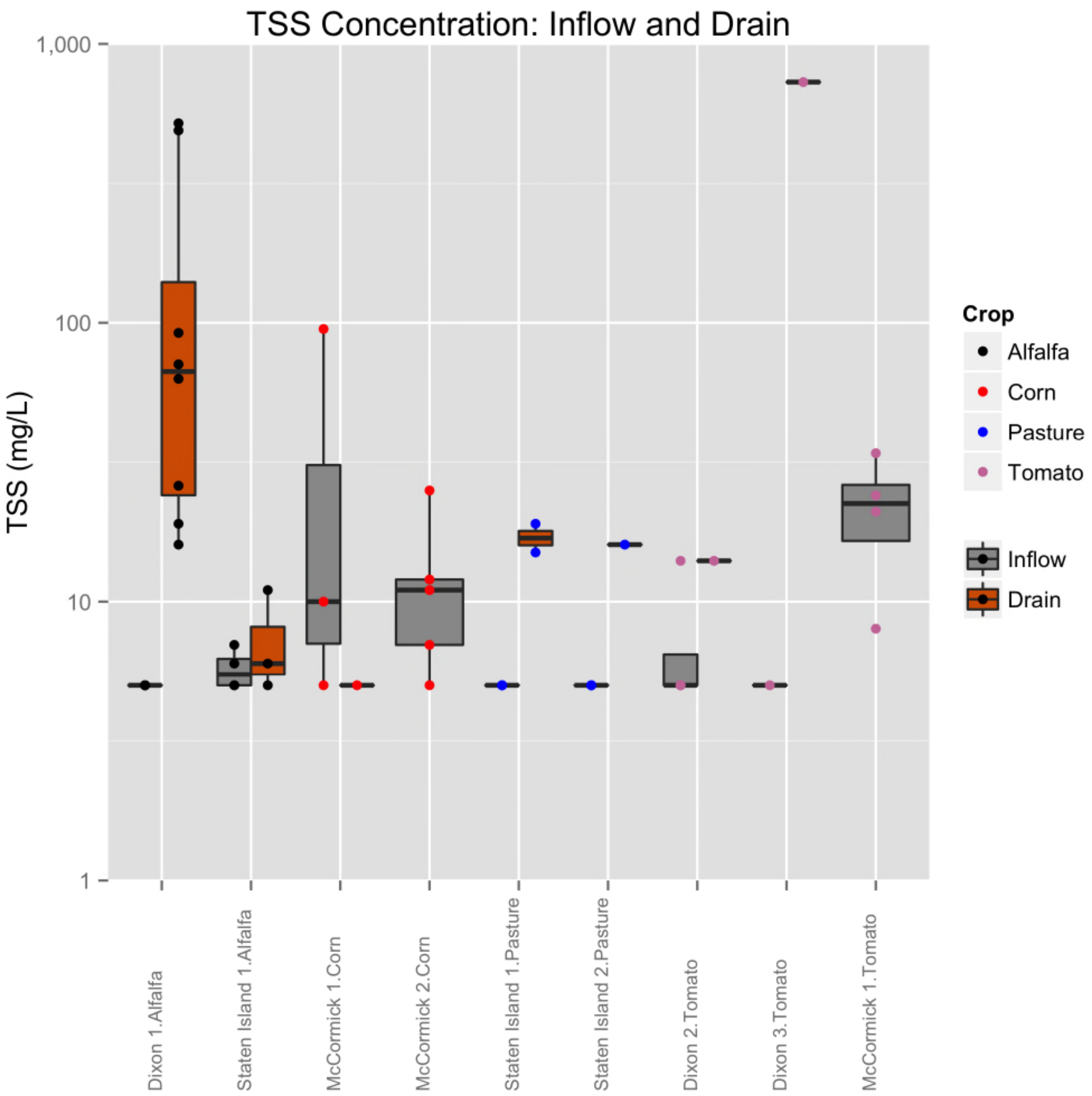


Figure 4-23 Comparison of inflows and drains: TSS

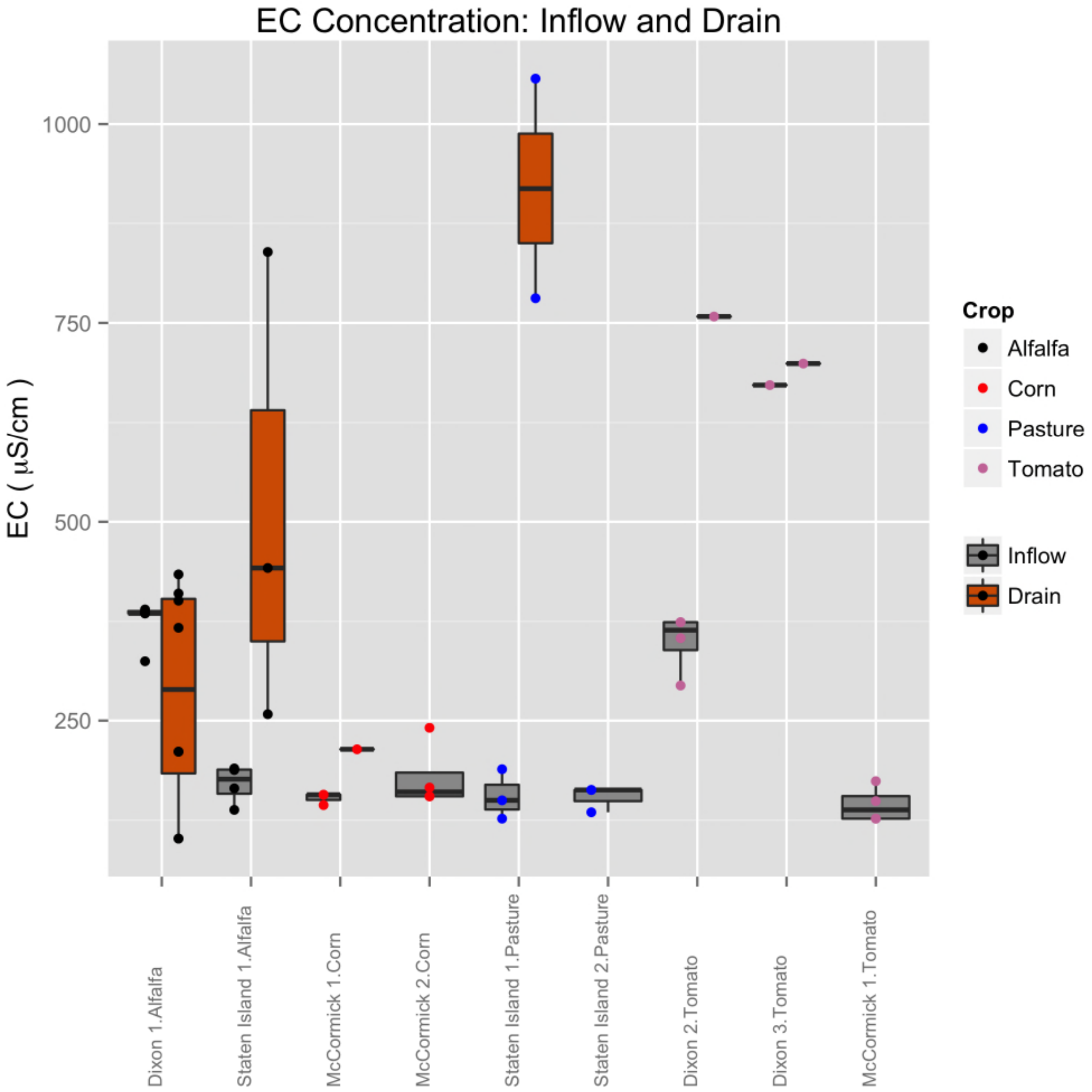


Figure 4-24 Comparison of inflows and drains: EC

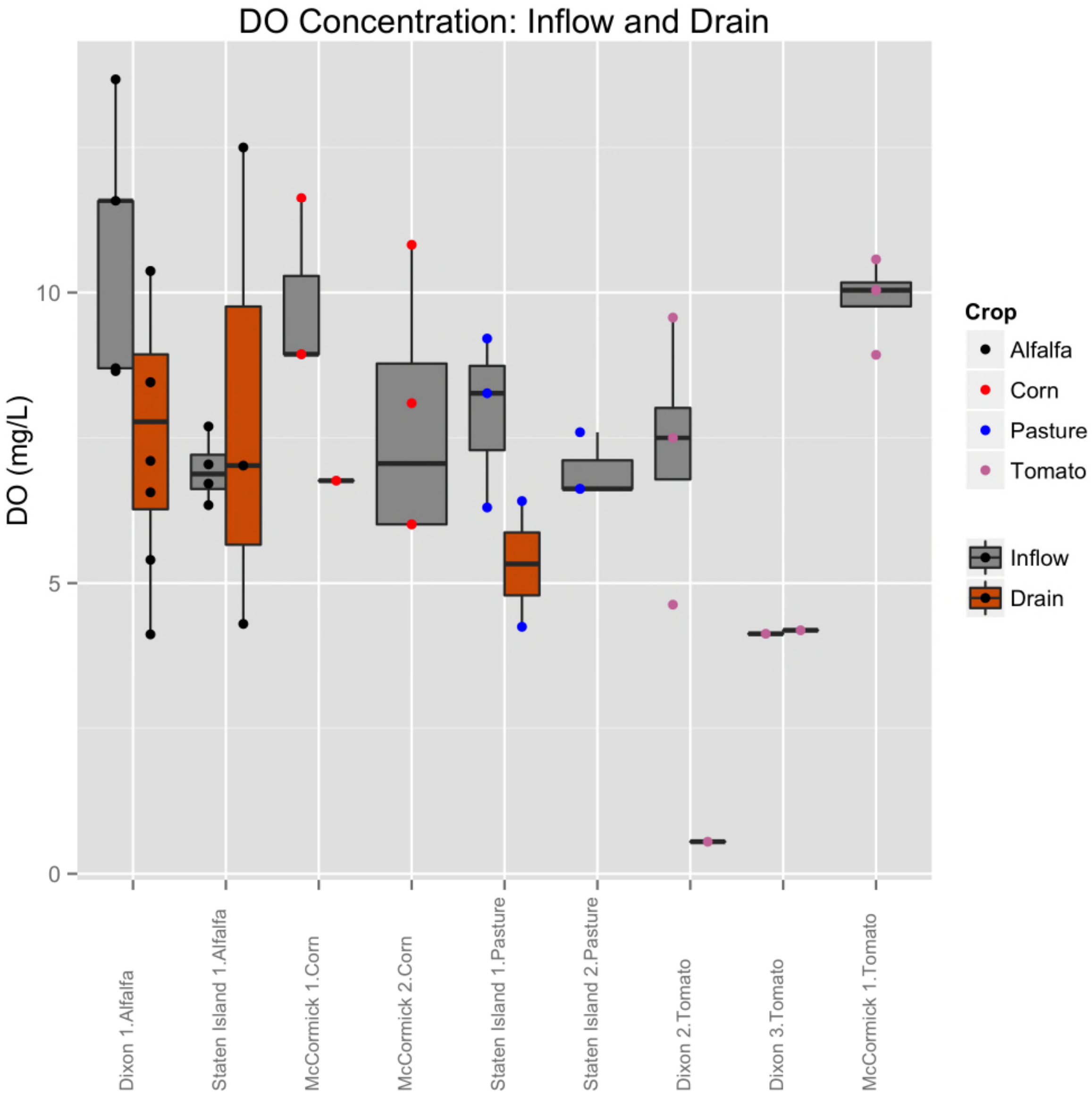


Figure 4-25 Comparison of inflows and drains: DO

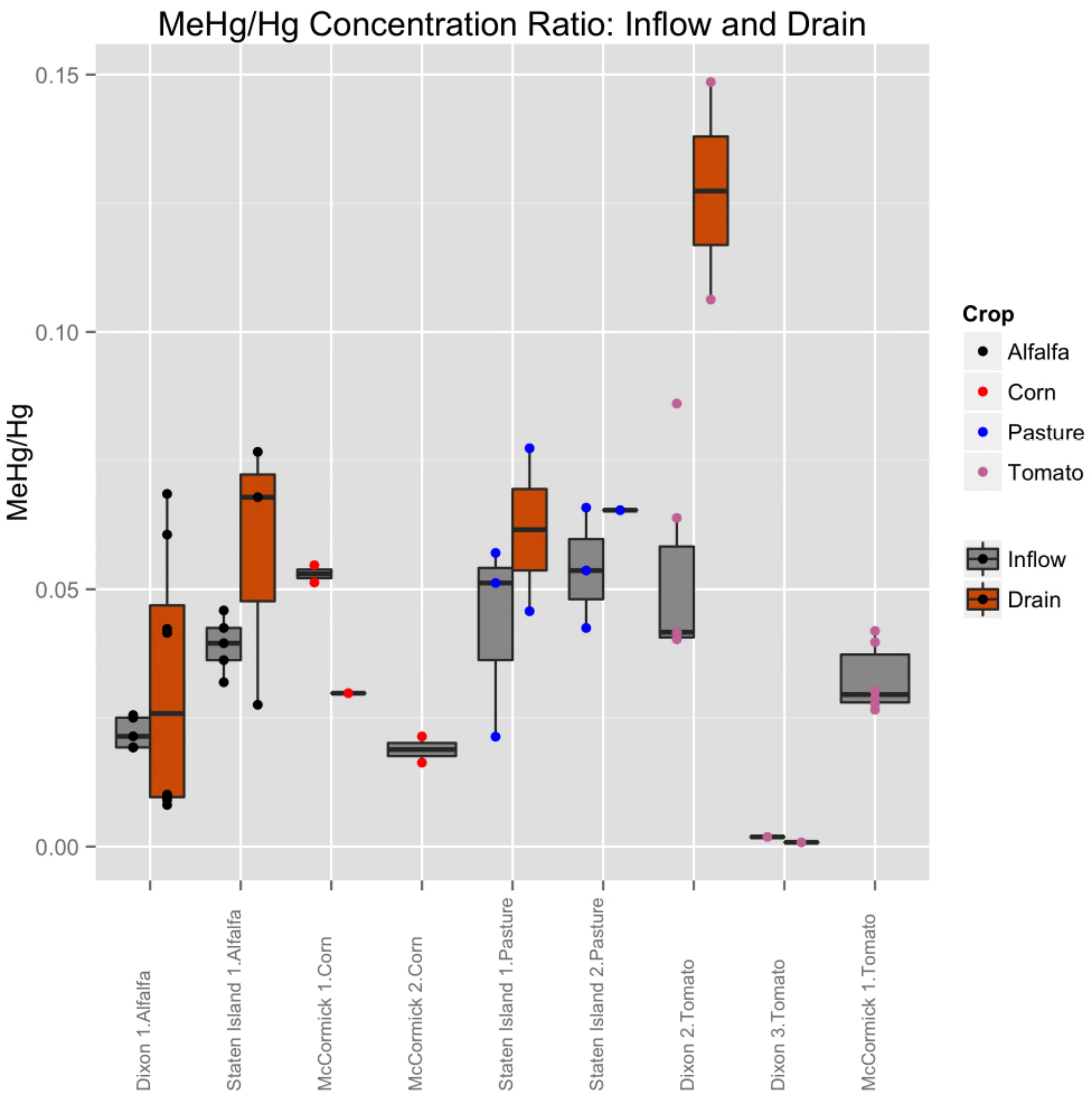


Figure 4-26 Comparison of inflows and drains: MeHg/Hg

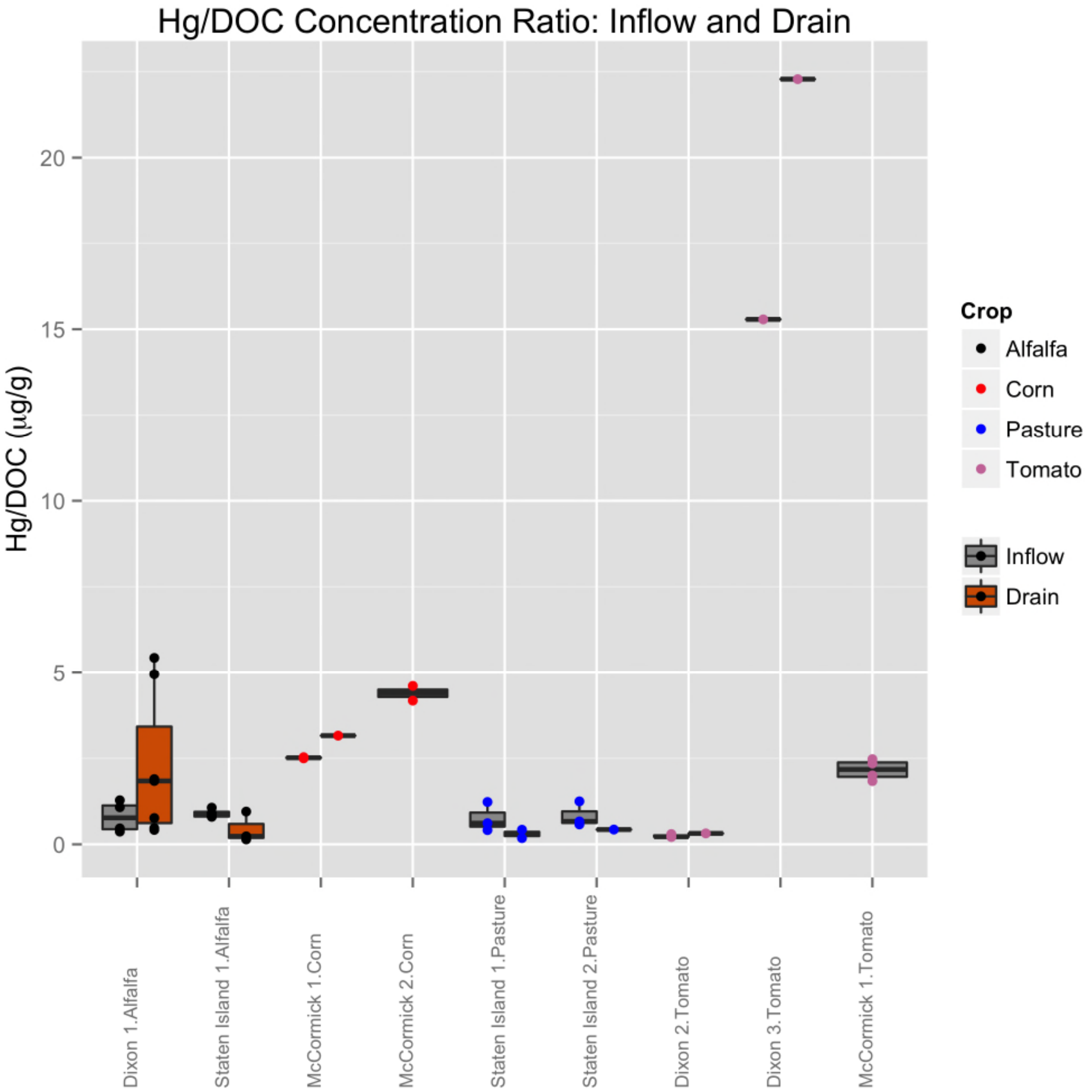


Figure 4-27 Comparison of inflows and drains: Hg/DOC

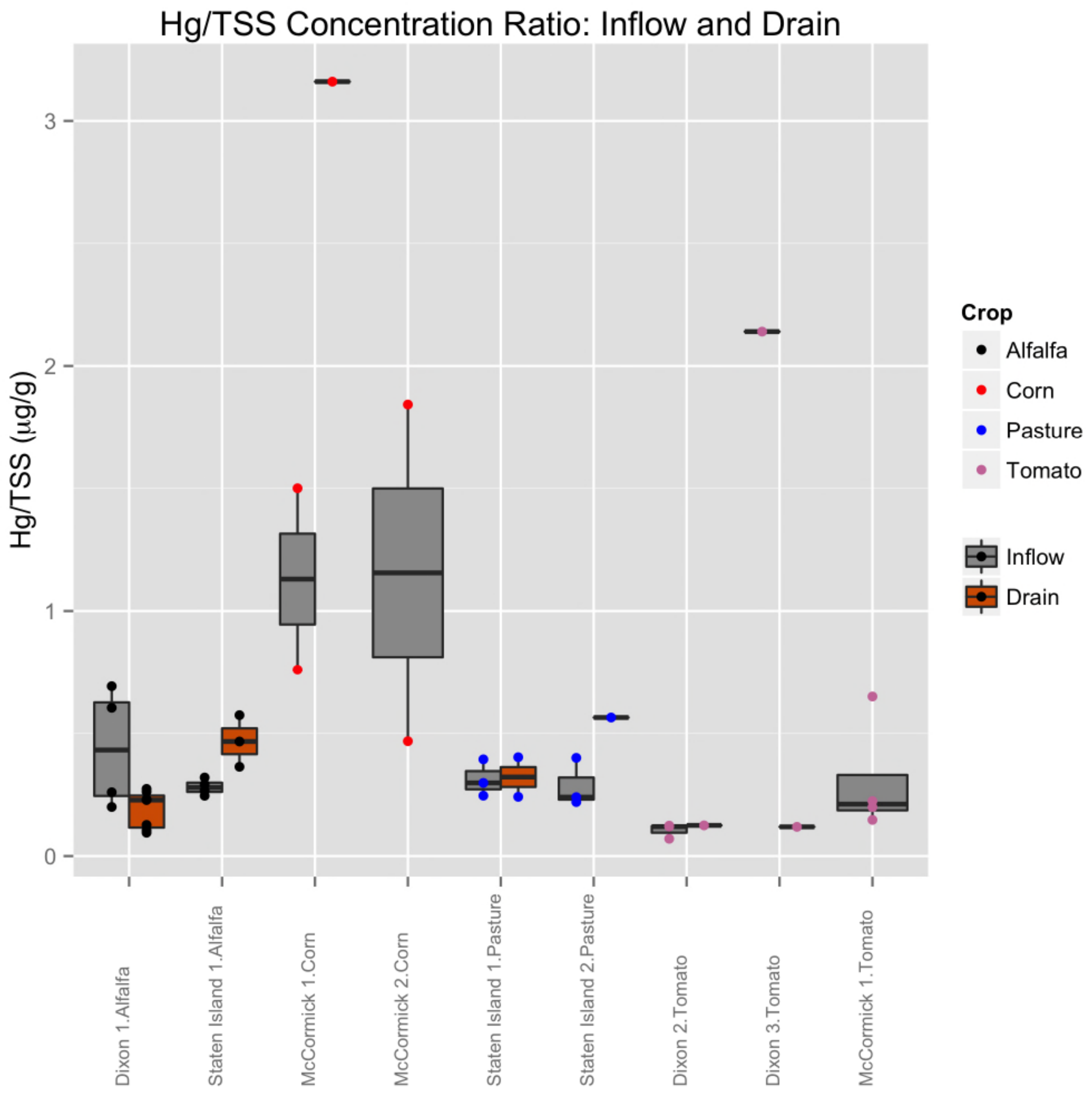


Figure 4-28 Comparison of inflows and drains: Hg/TSS

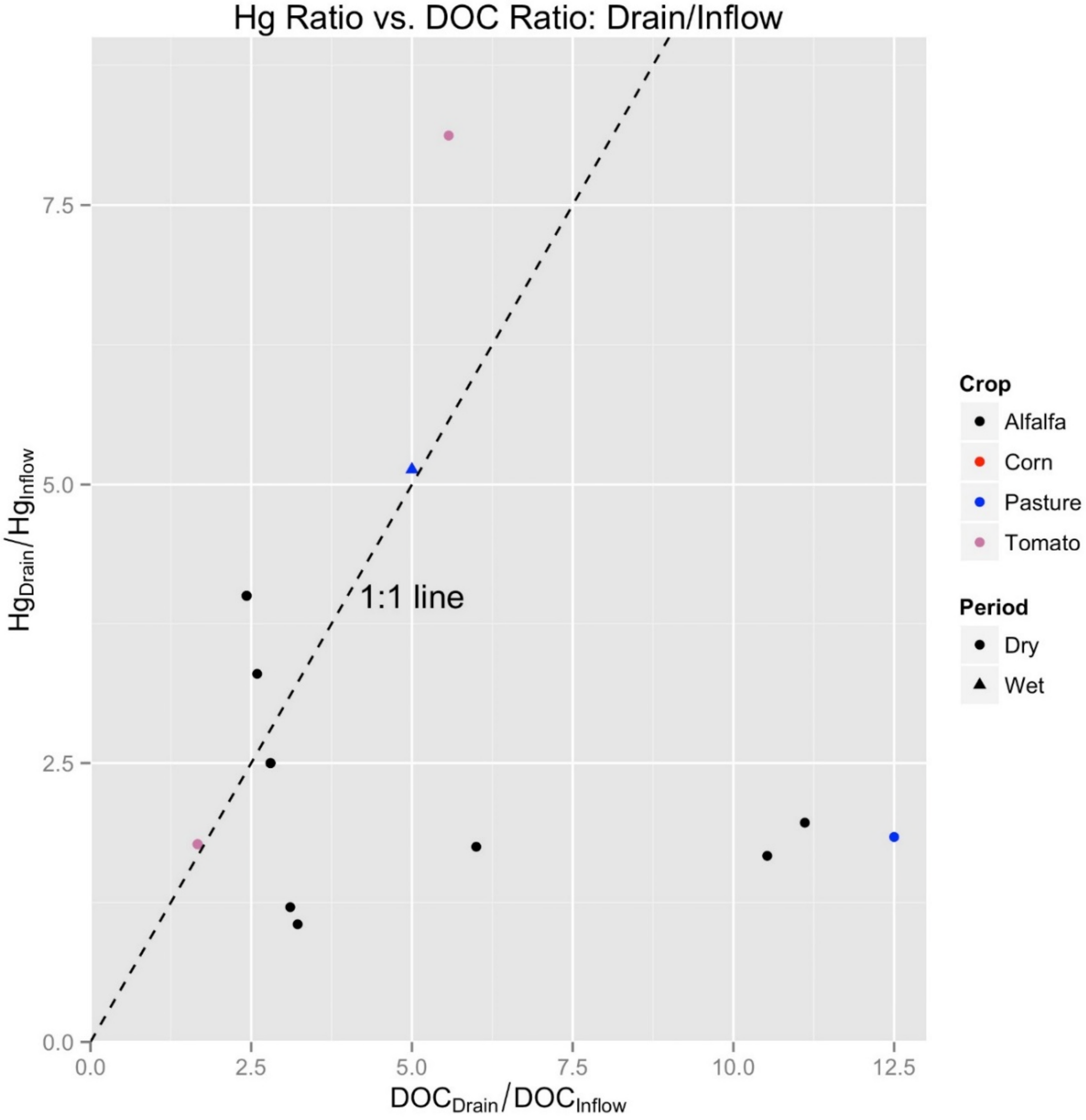


Figure 4-29 Ratio plot: DOC and Hg, Drain over inflow

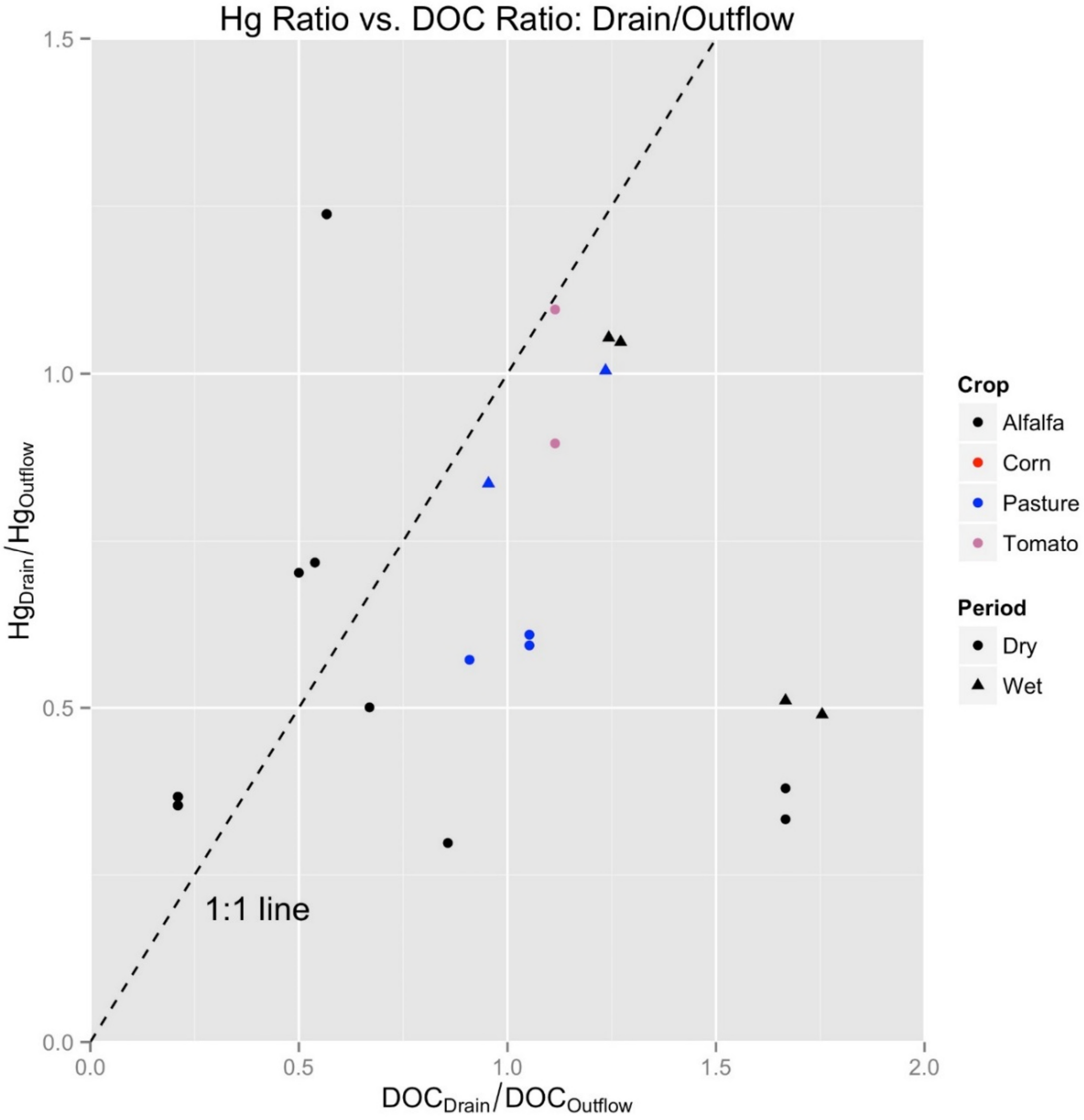


Figure 4-30 Ratio plot: DOC and Hg, Drain over outflow

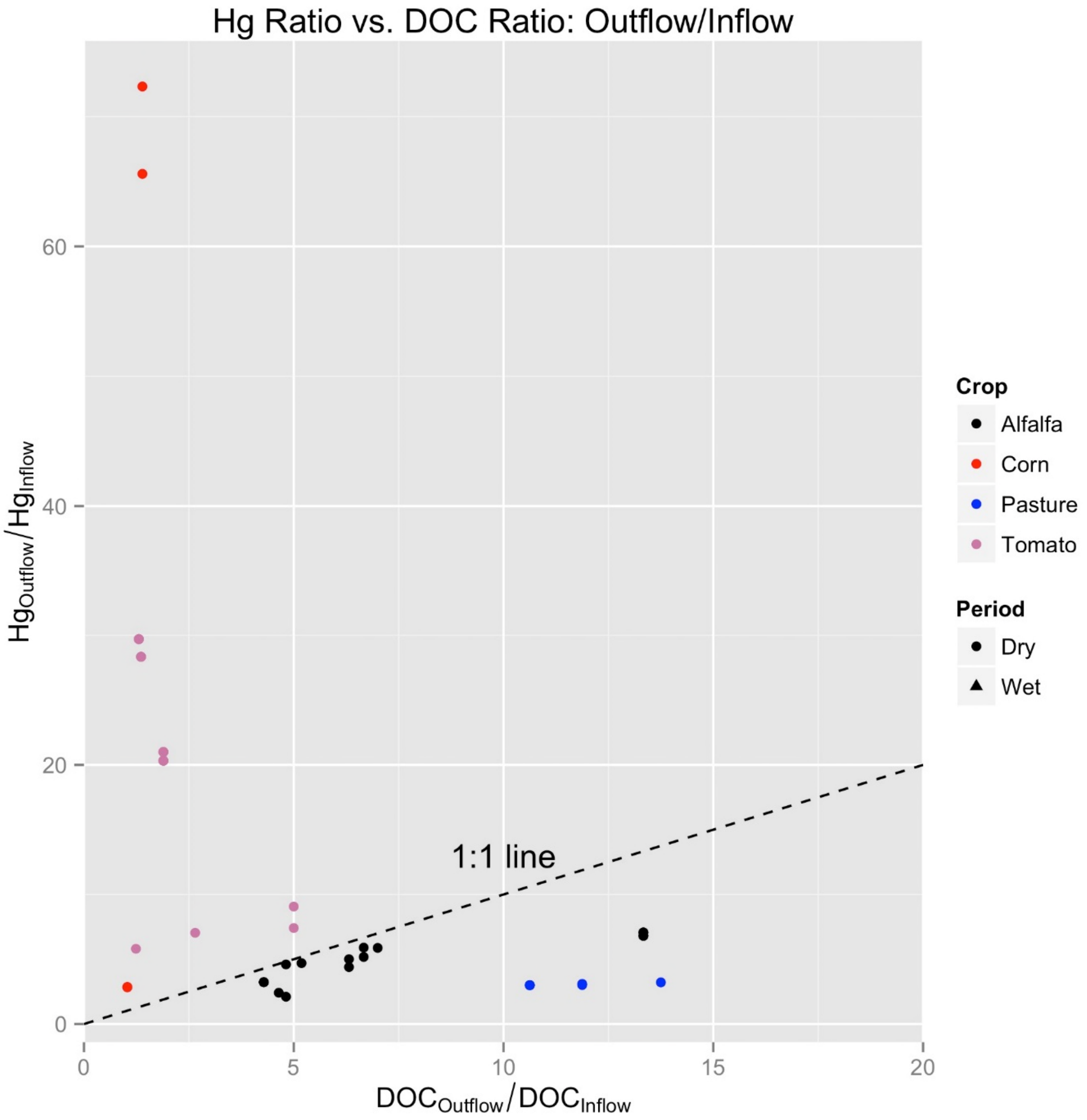


Figure 4-31 Ratio plot: DOC and Hg, outflow over inflow

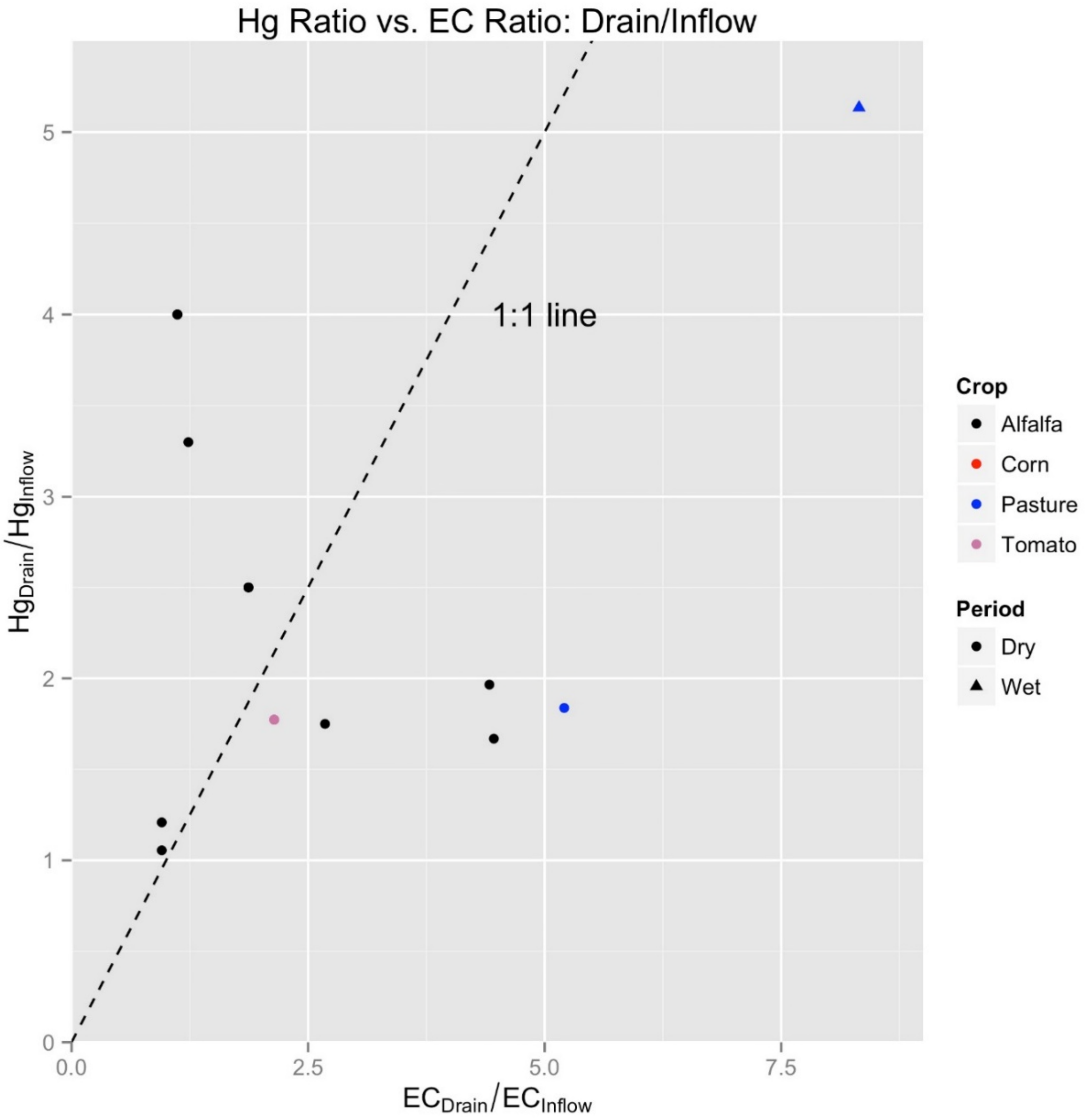


Figure 4-32 Ratio plot: EC and Hg, Drain over inflow

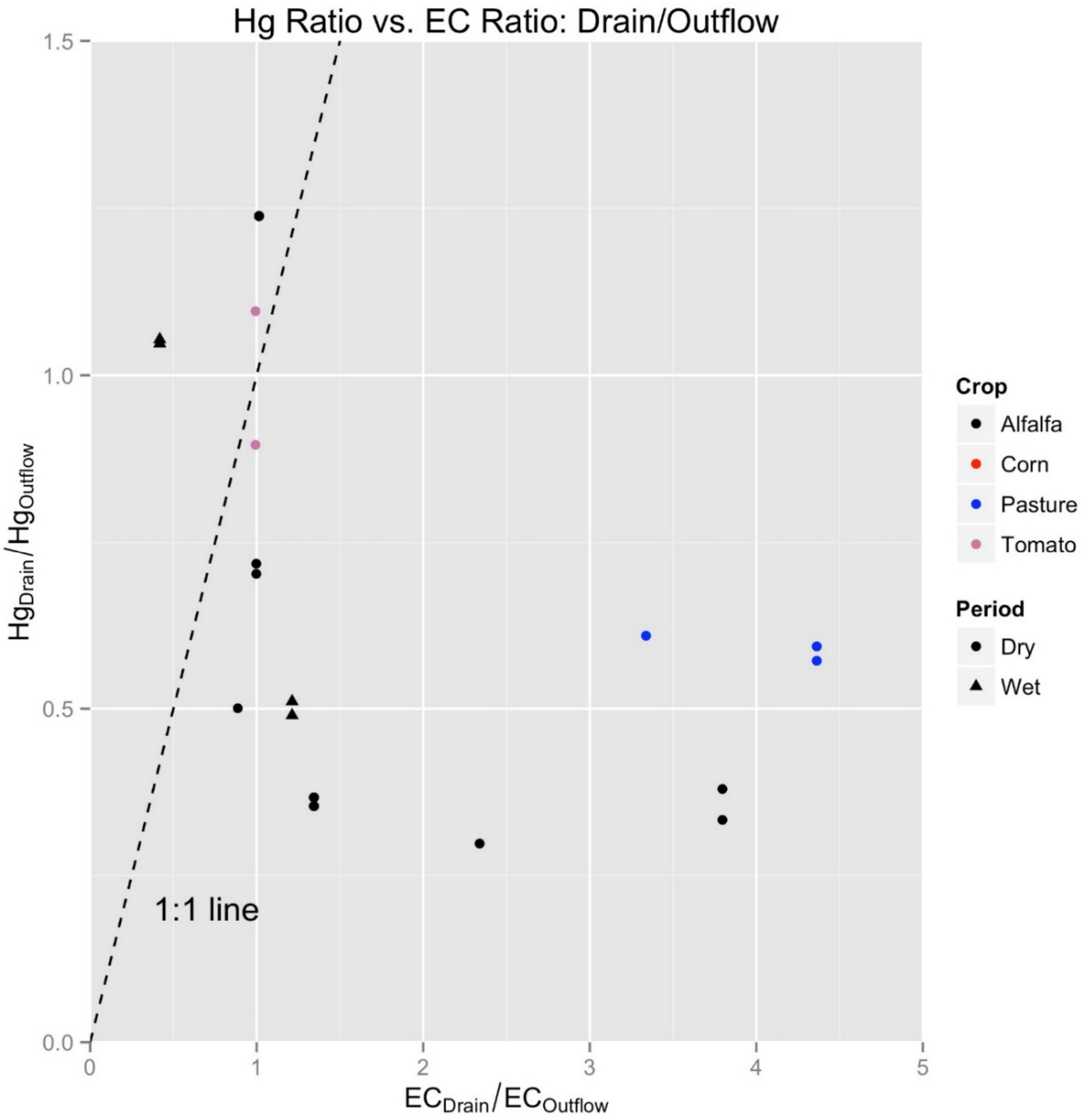


Figure 4-33 Ratio plot: EC and Hg, Drain over outflow

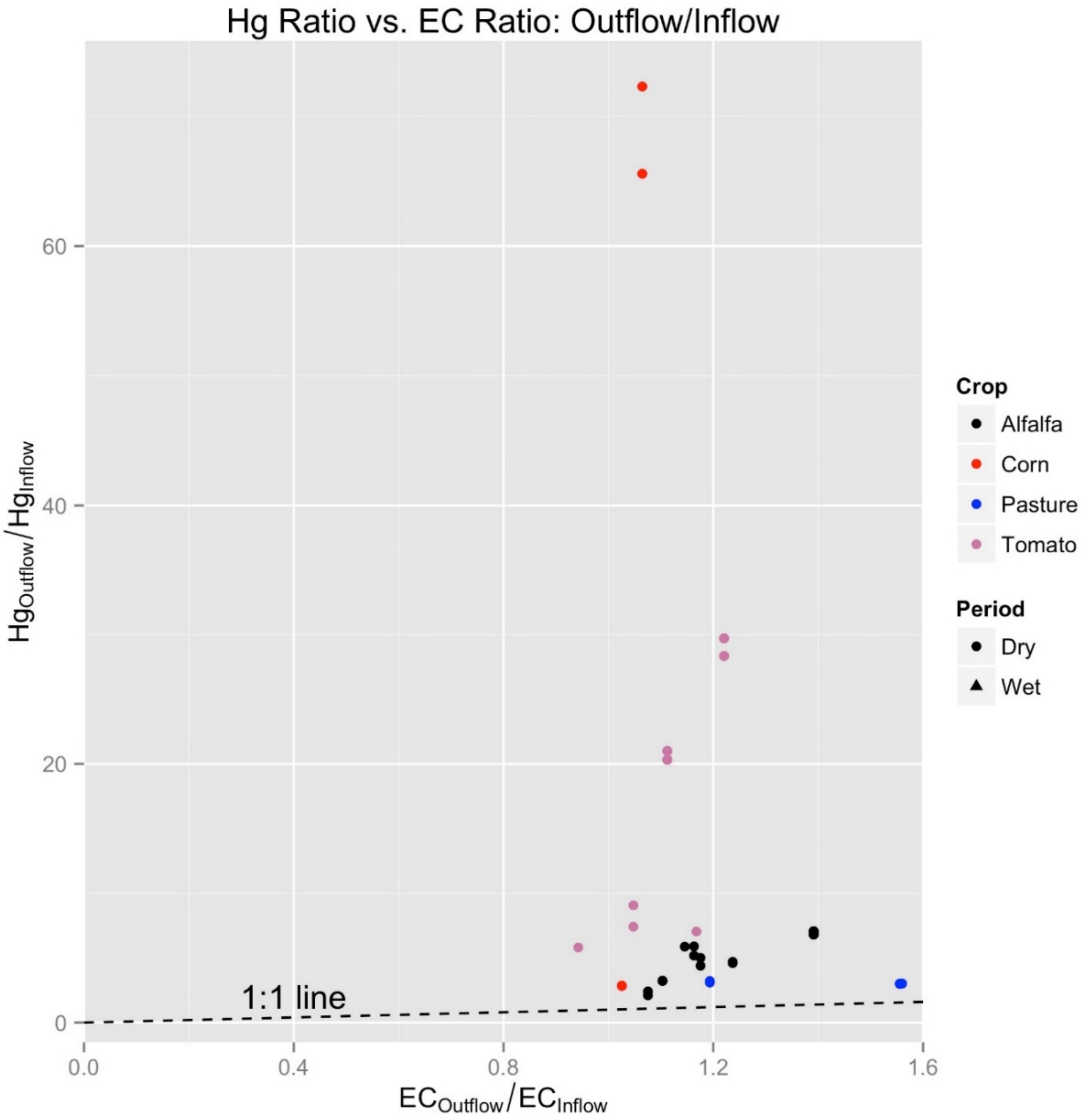


Figure 4-34 Ratio plot: EC and Hg, Outflow over inflow

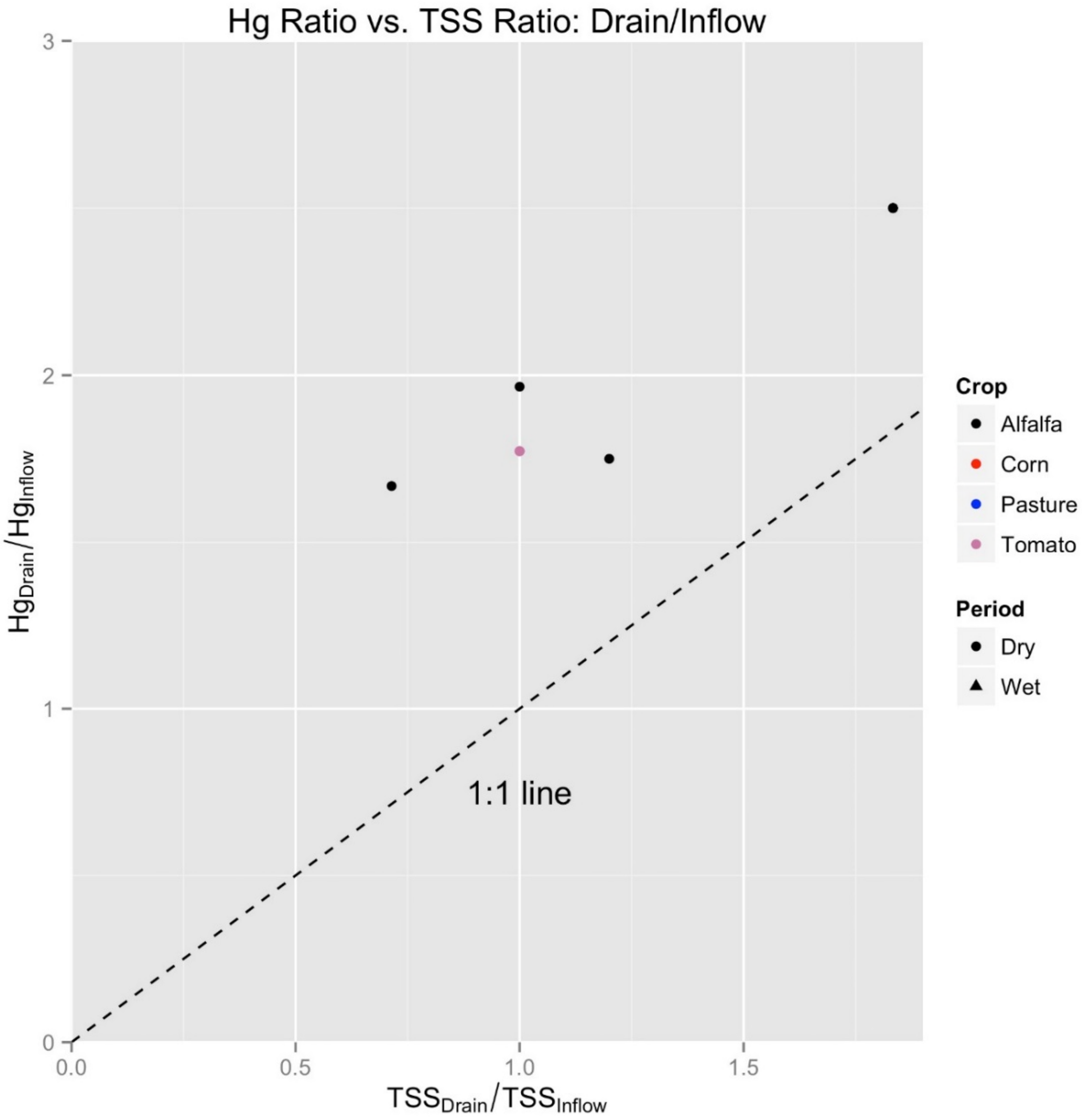


Figure 4-35 Ratio plot: TSS and Hg, Drain over inflow

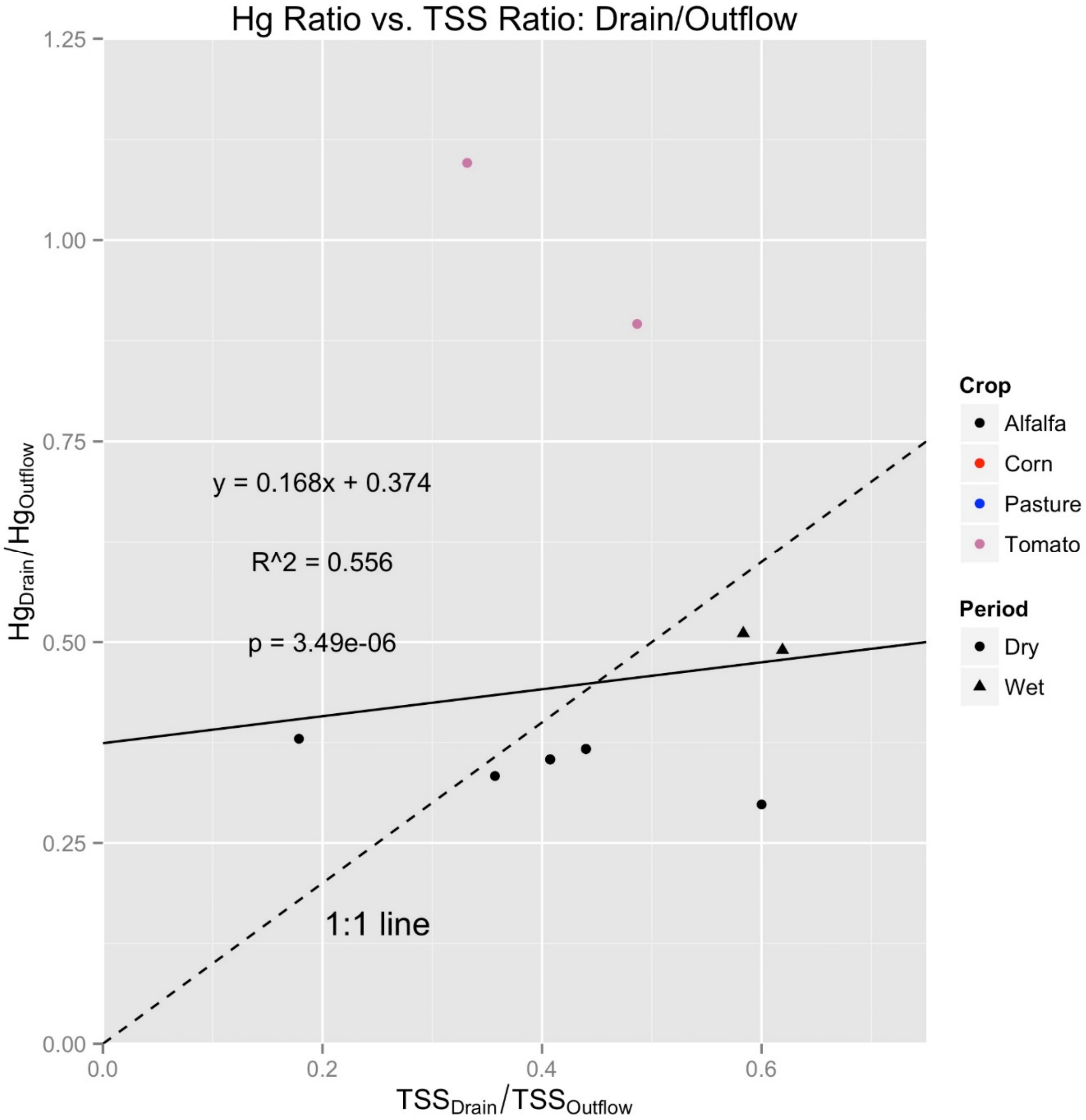


Figure 4-36 Ratio plot: TSS and Hg, Drain over outflow. Solid line is best fit linear regression (statistically significant).

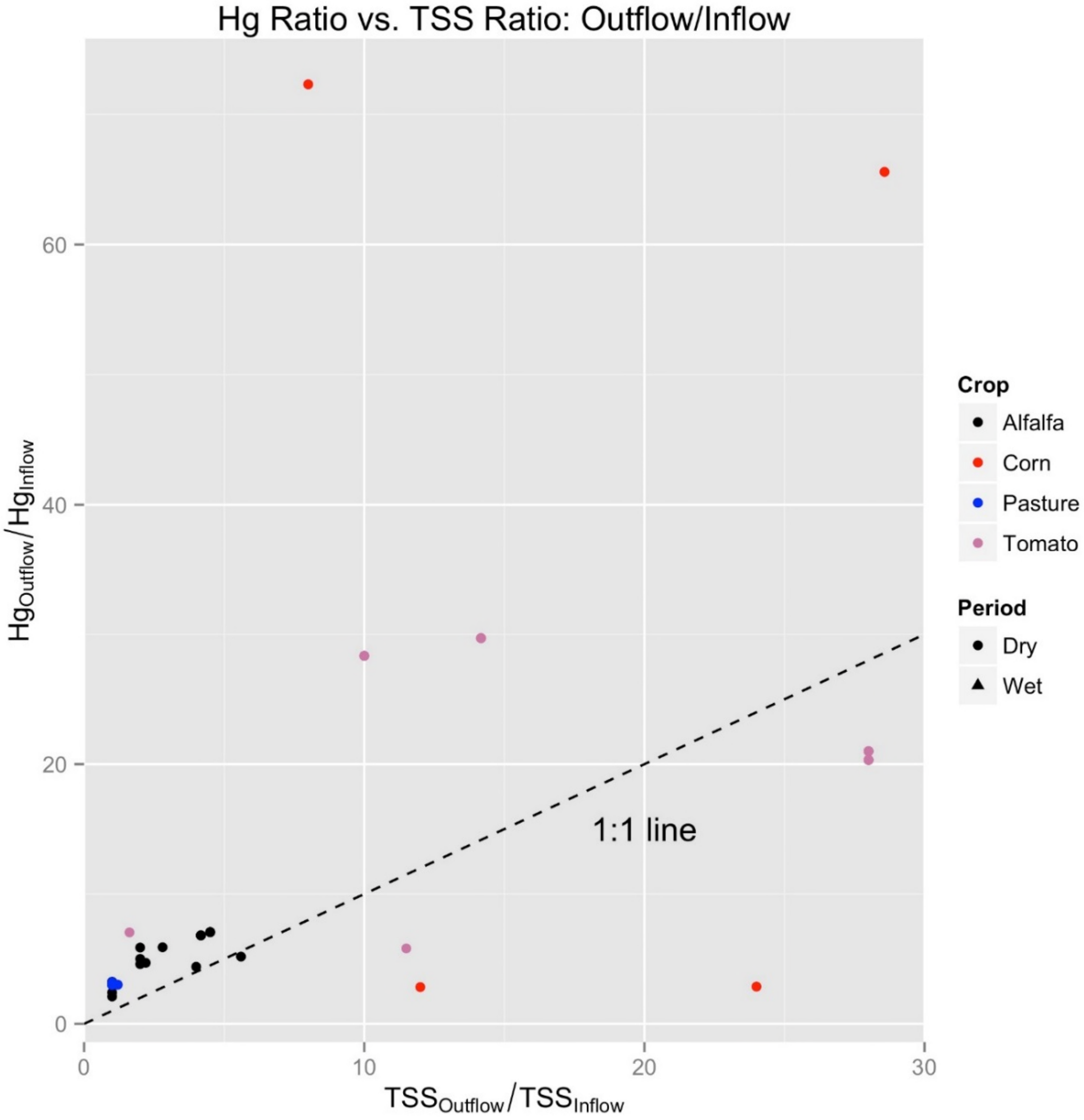


Figure 4-37 Ratio plot: TSS and Hg, outflow over inflow

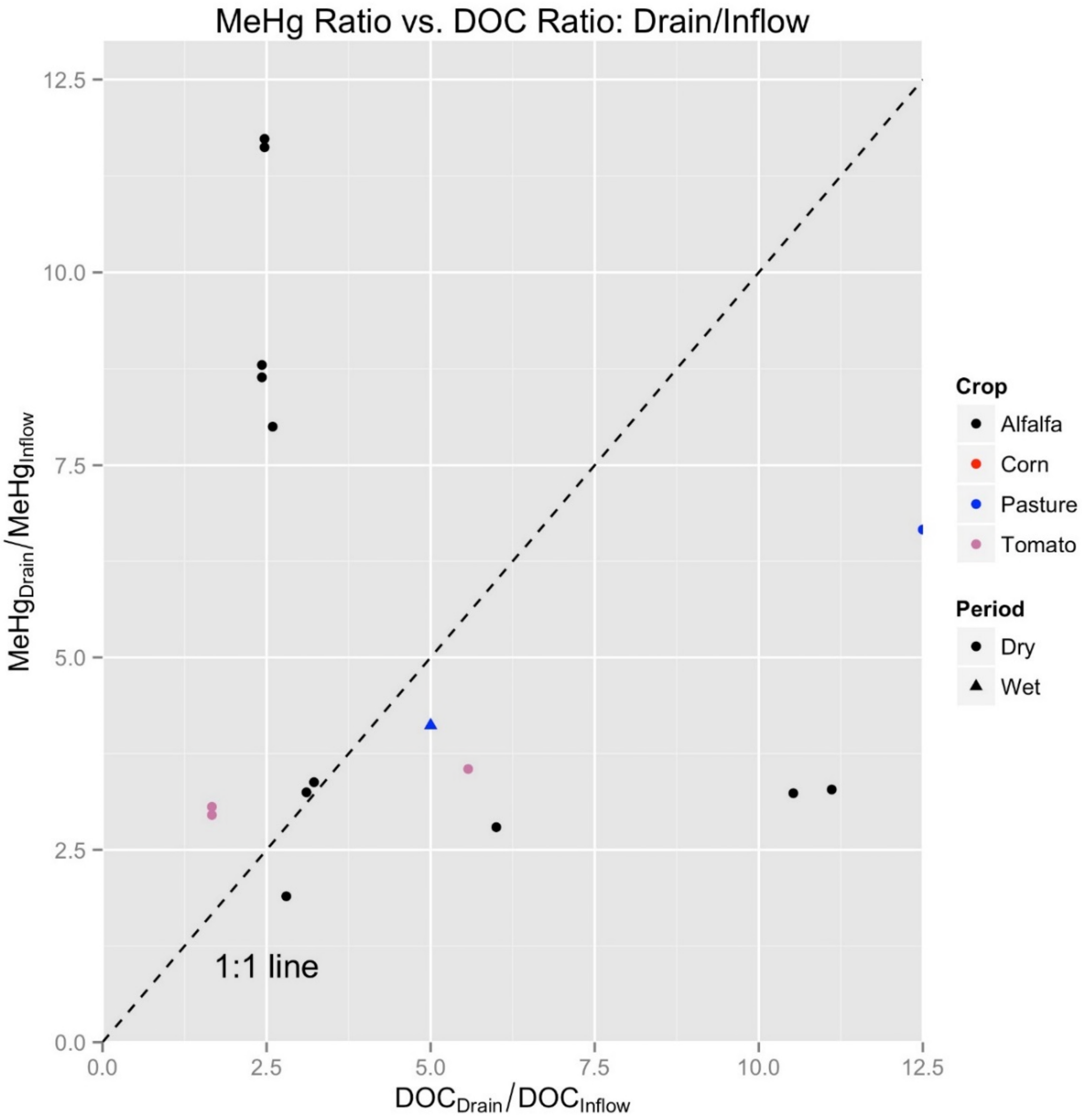


Figure 4-38 Ratio plot: DOC and MeHg, Drain over inflow

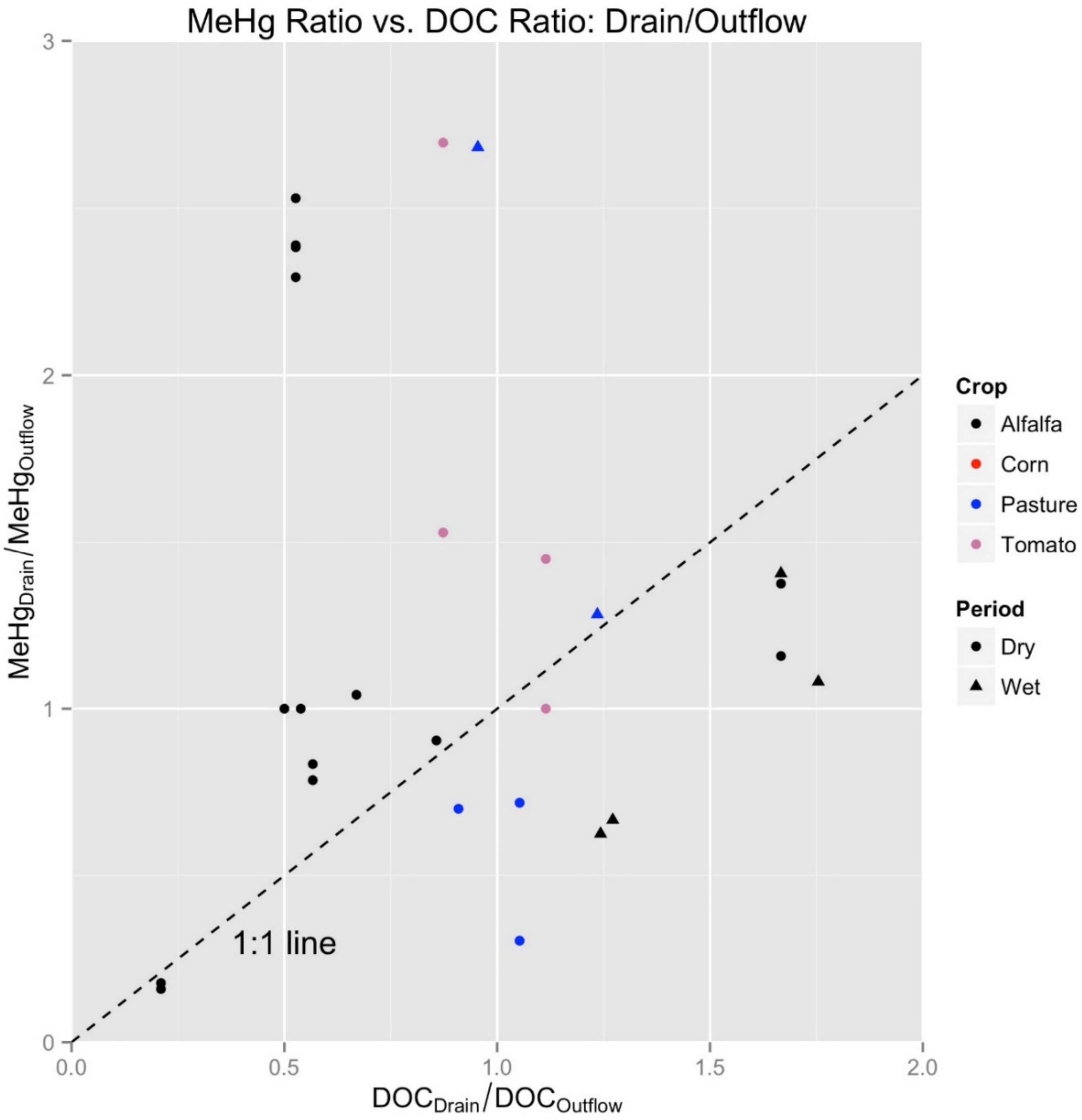


Figure 4-39 Ratio plot: DOC and MeHg, Drain over outflow

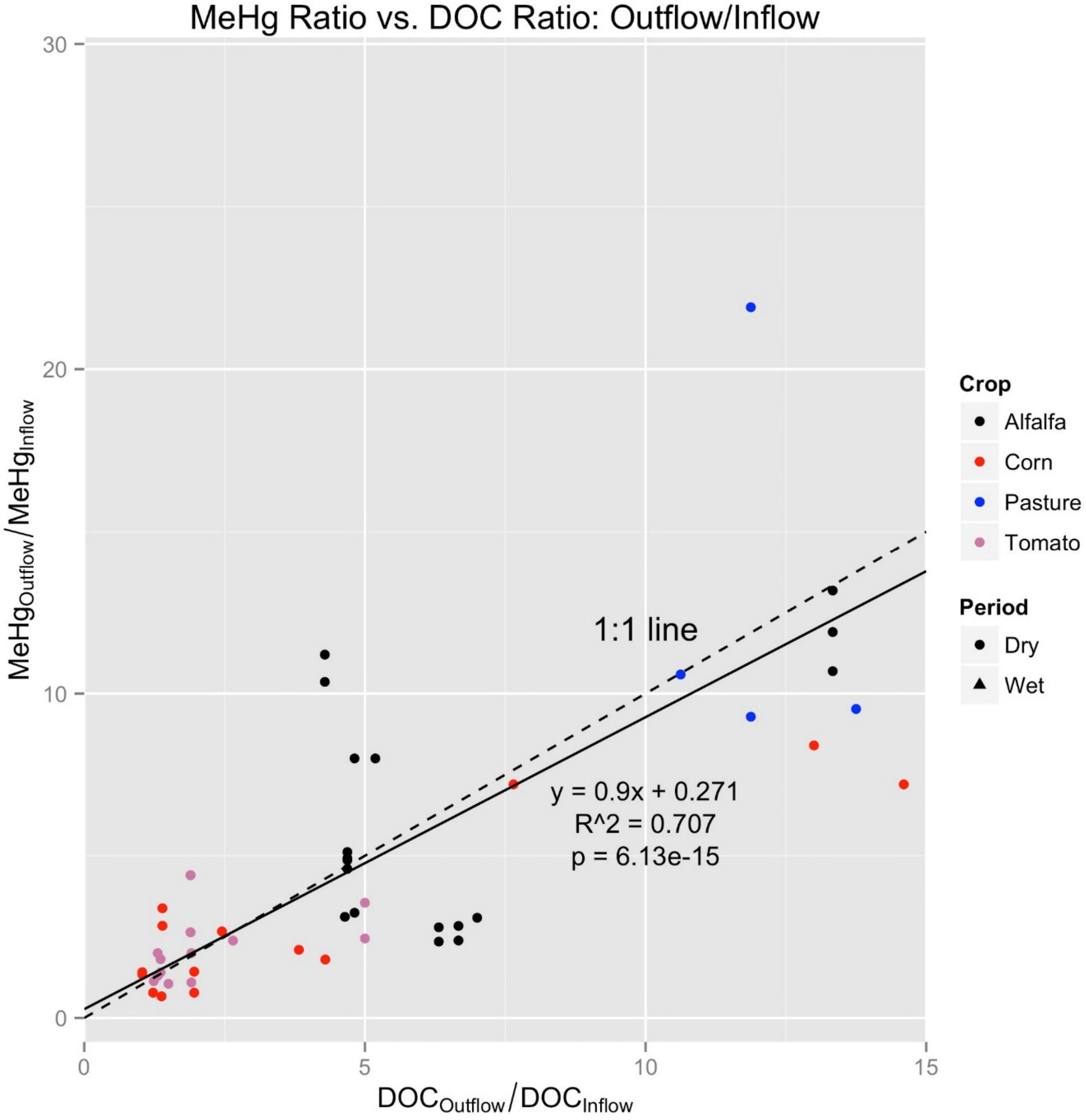


Figure 4-40 *Ratio plot: DOC and MeHg, Outflow over inflow. Solid line is best fit linear regression (statistically significant).*

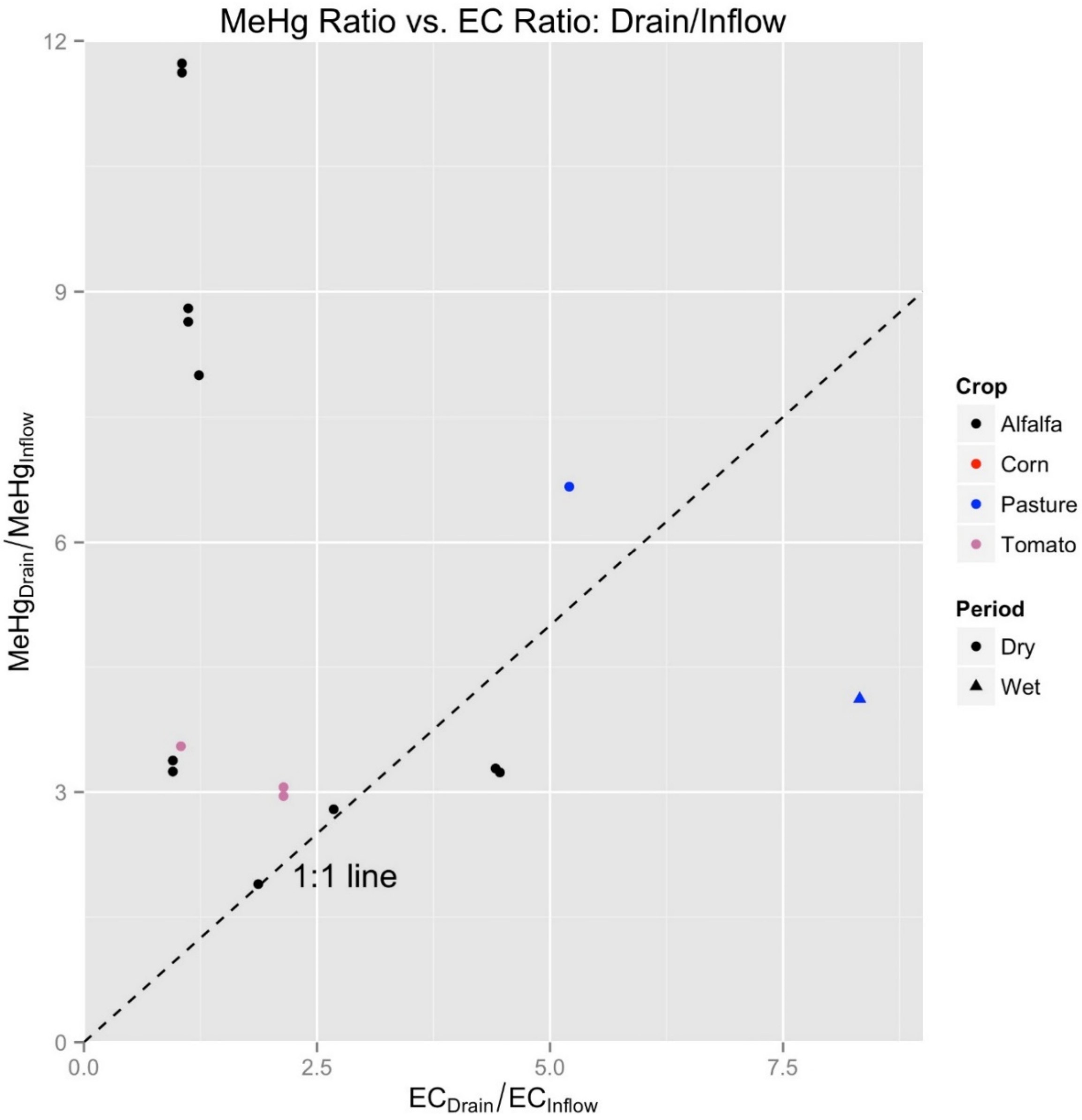


Figure 4-41 Ratio plot: EC and MeHg, Drain over inflow

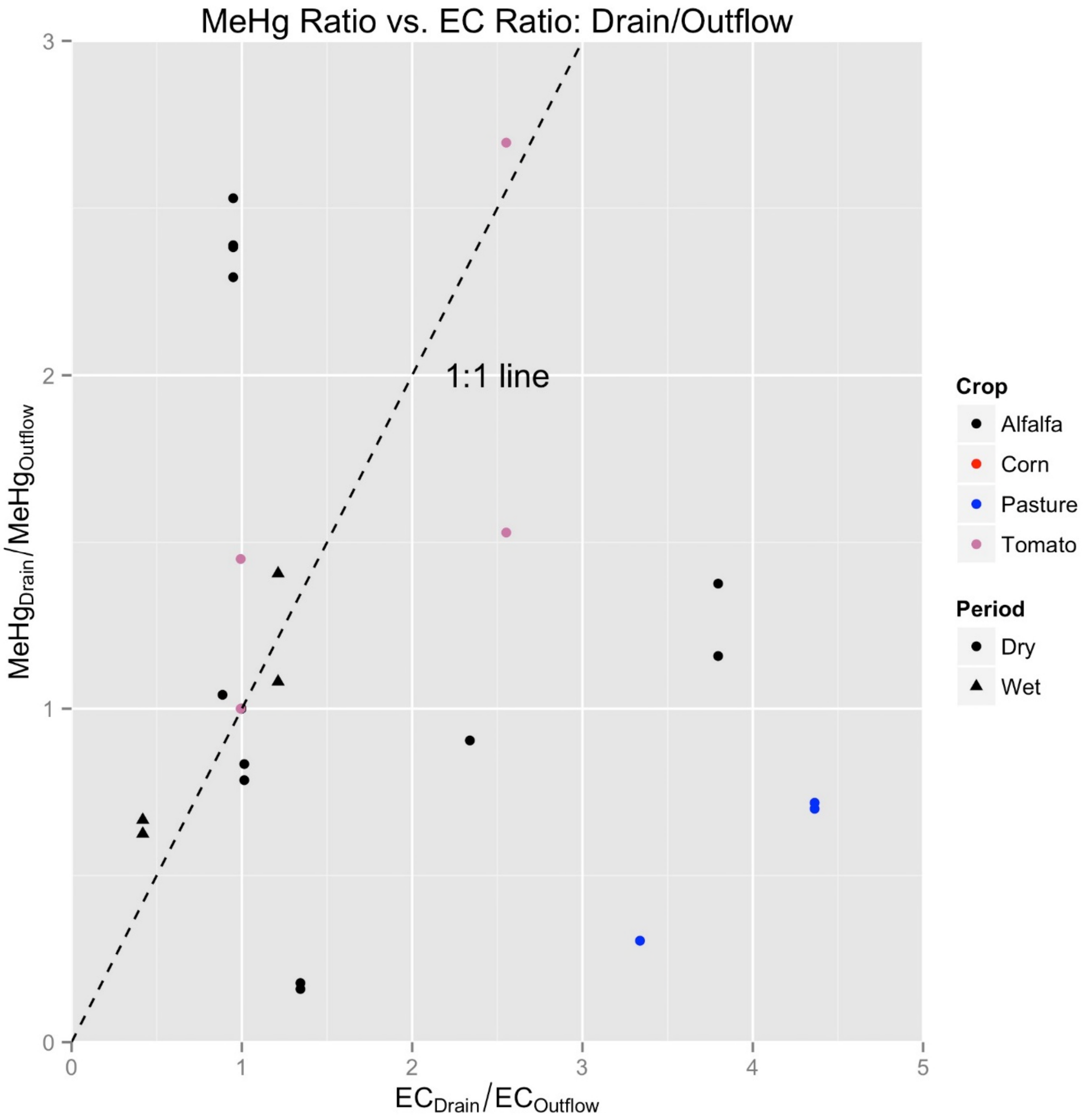


Figure 4-42 Ratio plot: EC and MeHg, Drain over outflow

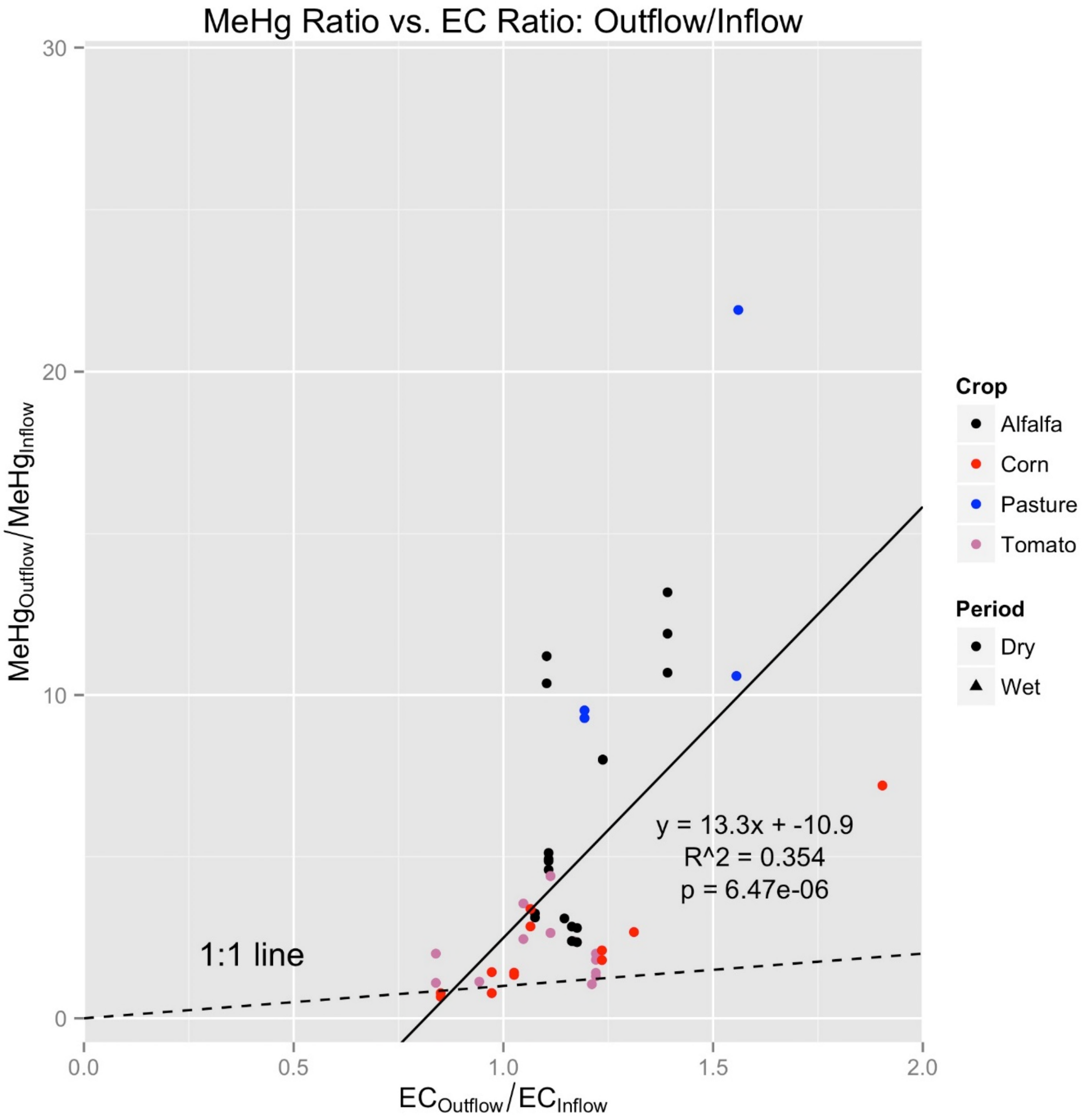


Figure 4-43 *Ratio plot: EC and MeHg, Outflow over inflow. Solid line is best fit linear regression (statistically significant).*

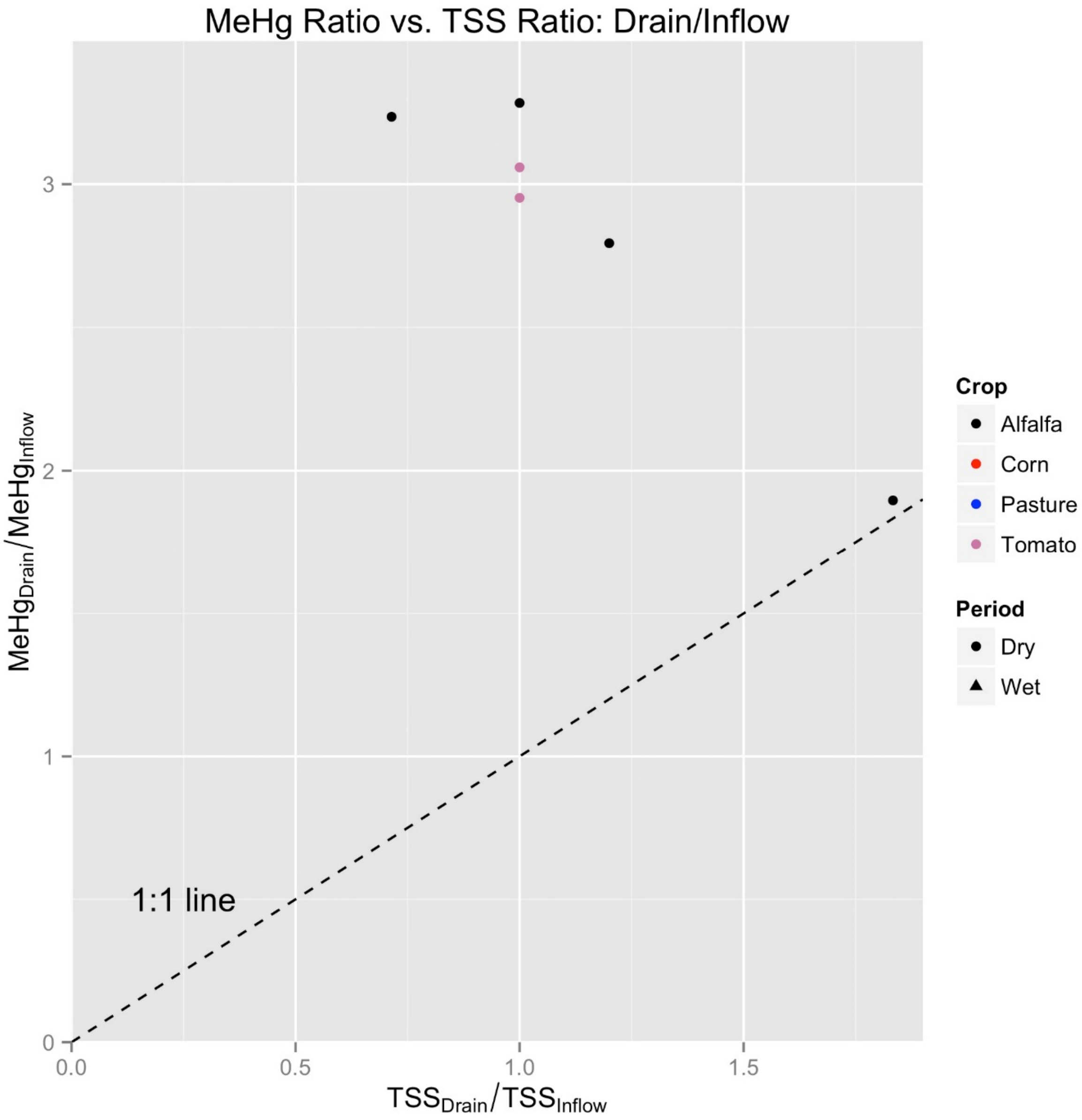


Figure 4-44 Ratio plot: TSS and MeHg, Drain over inflow

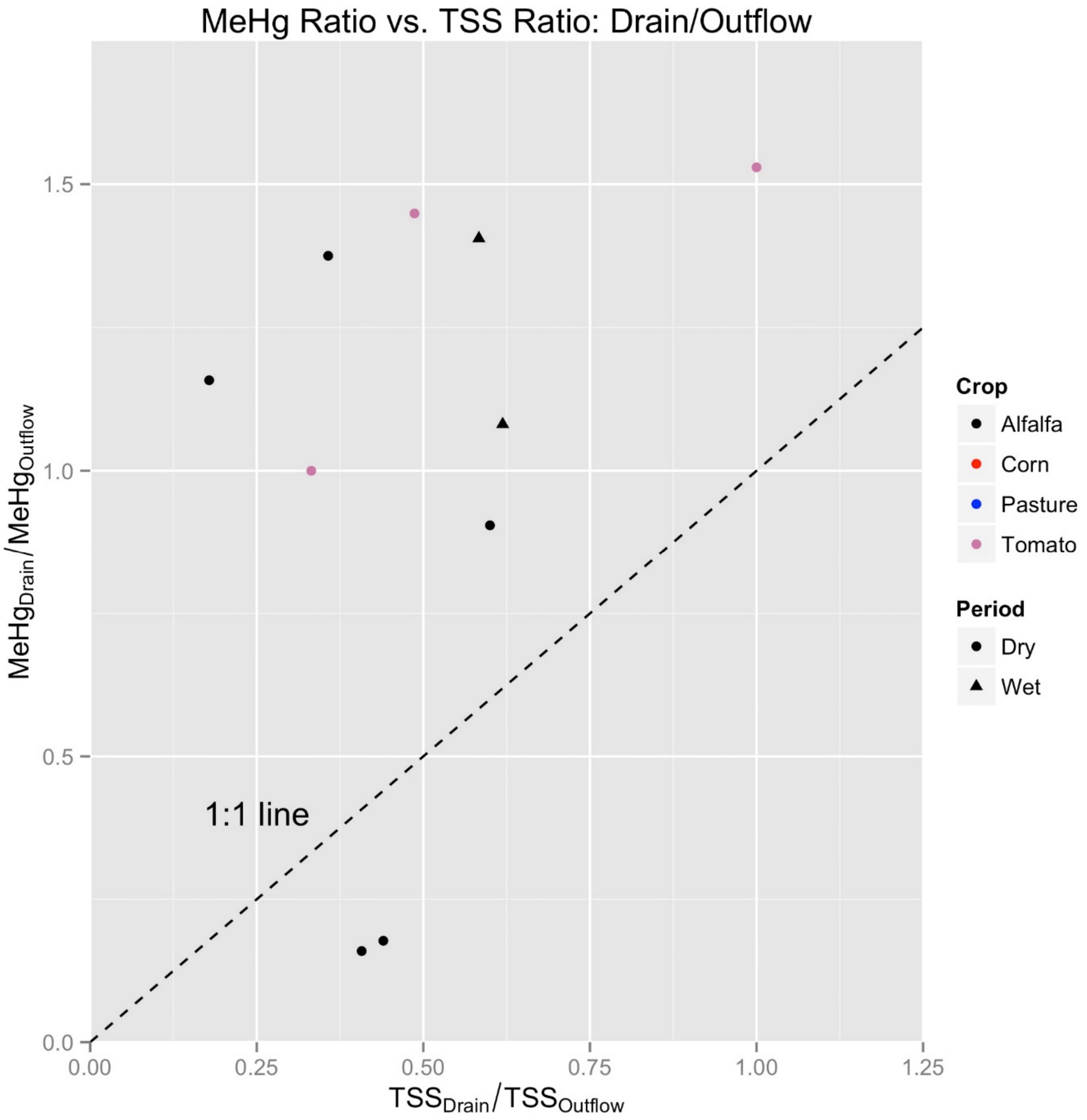


Figure 4-45 Ratio plot: TSS and MeHg, Drain over outflow

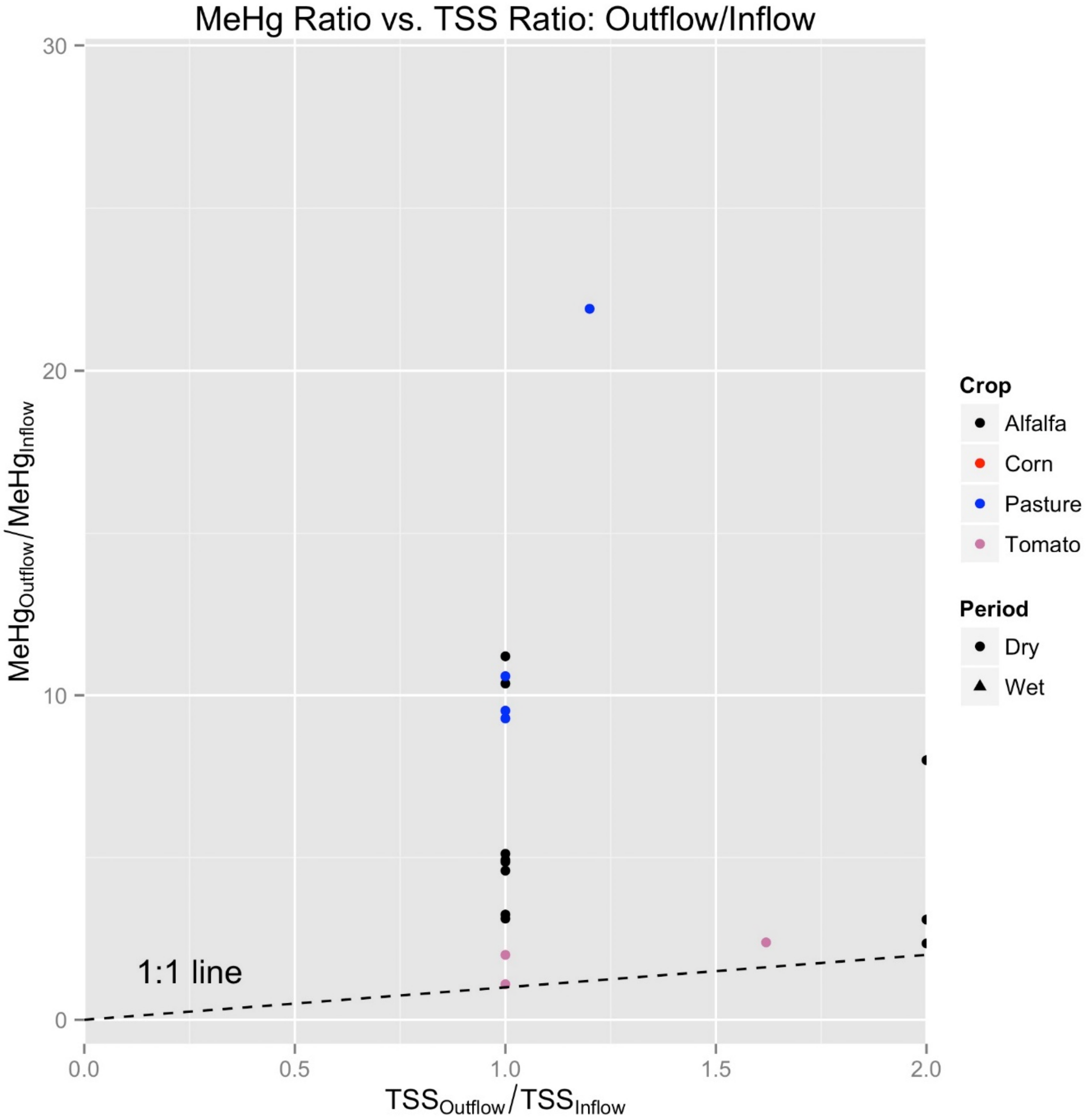


Figure 4-46 Ratio plot: TSS and MeHg, Outflow over inflow

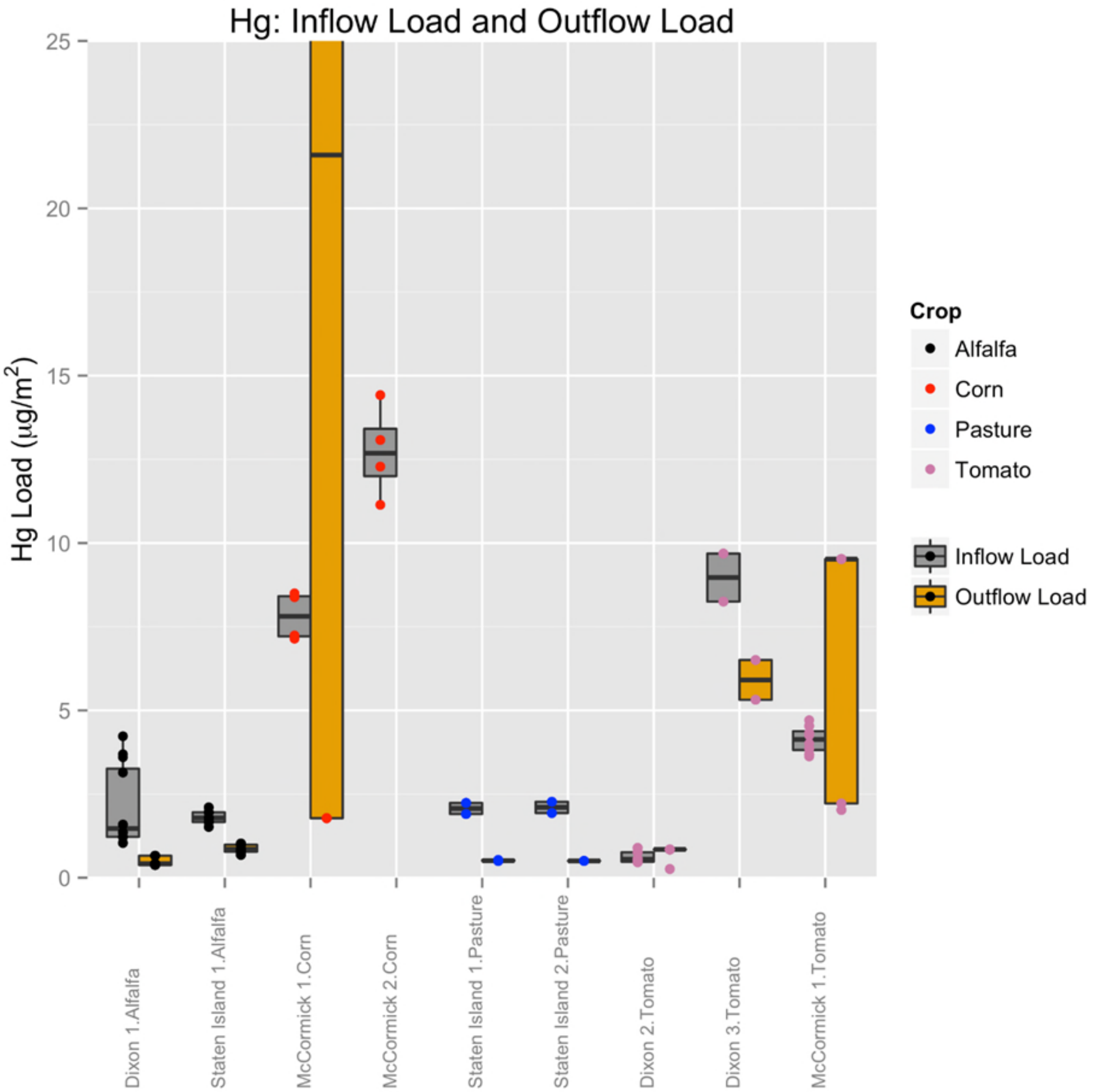


Figure 4-47 Load estimate (inflow and outflow) for total Hg, runoff = 10% of water application, percolation = 5-25% of water application.

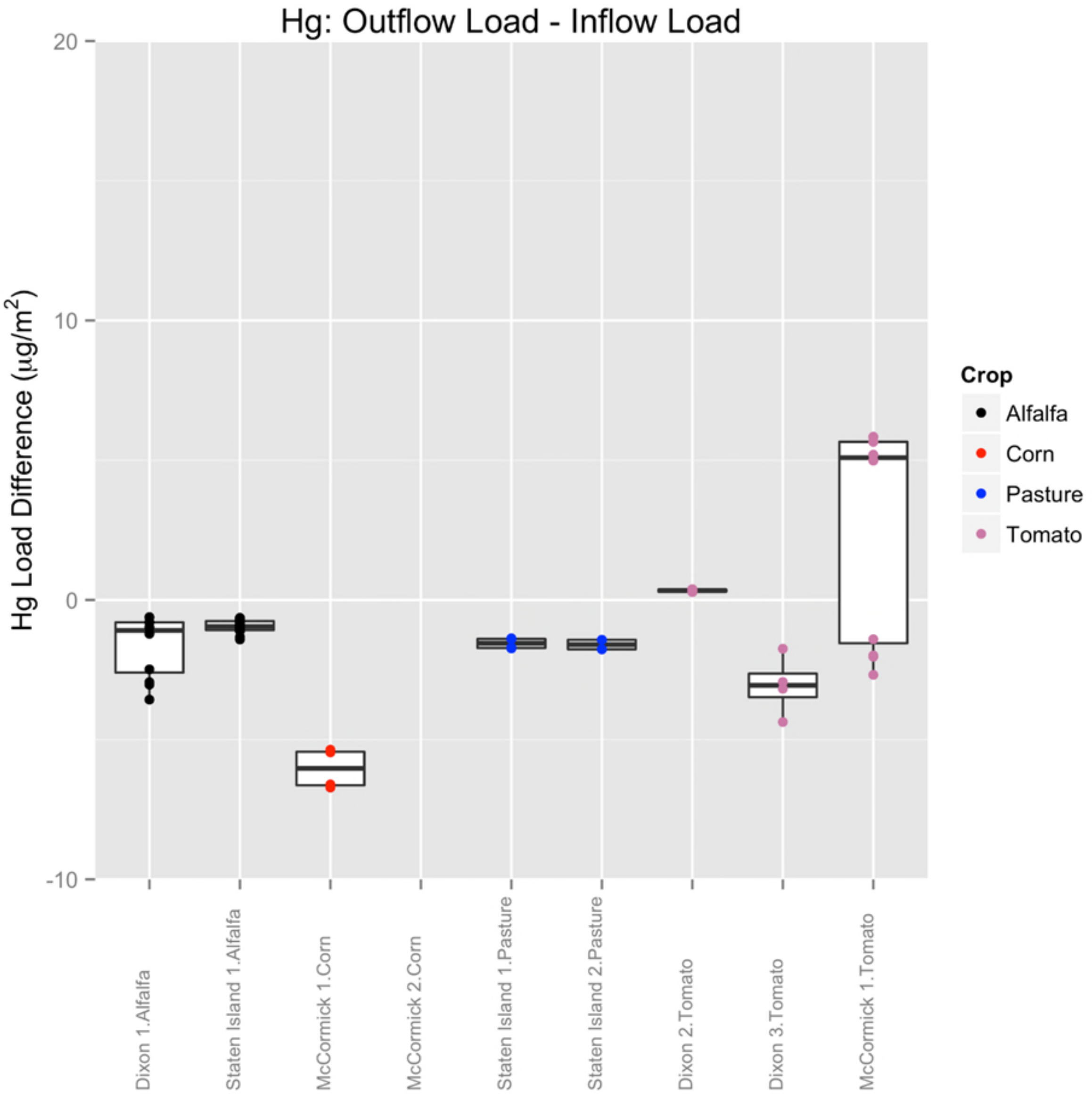


Figure 4-48 Load estimate (net load) for total Hg, runoff = 10% of water application, percolation = 5-25% of water application.

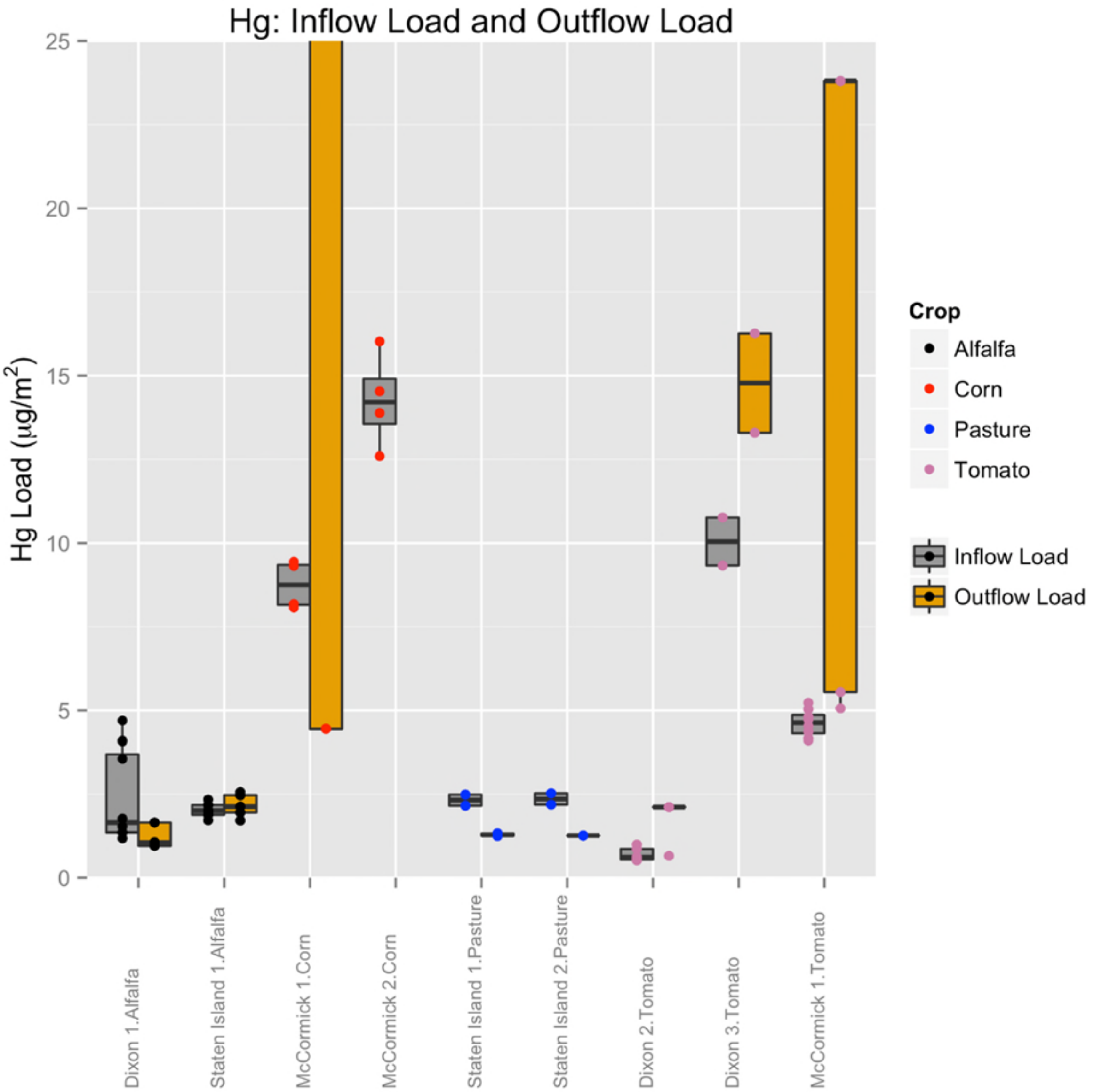


Figure 4-49 Load estimate (net load) for total Hg, runoff = 25% of water application, percolation = 5-25% of water application.

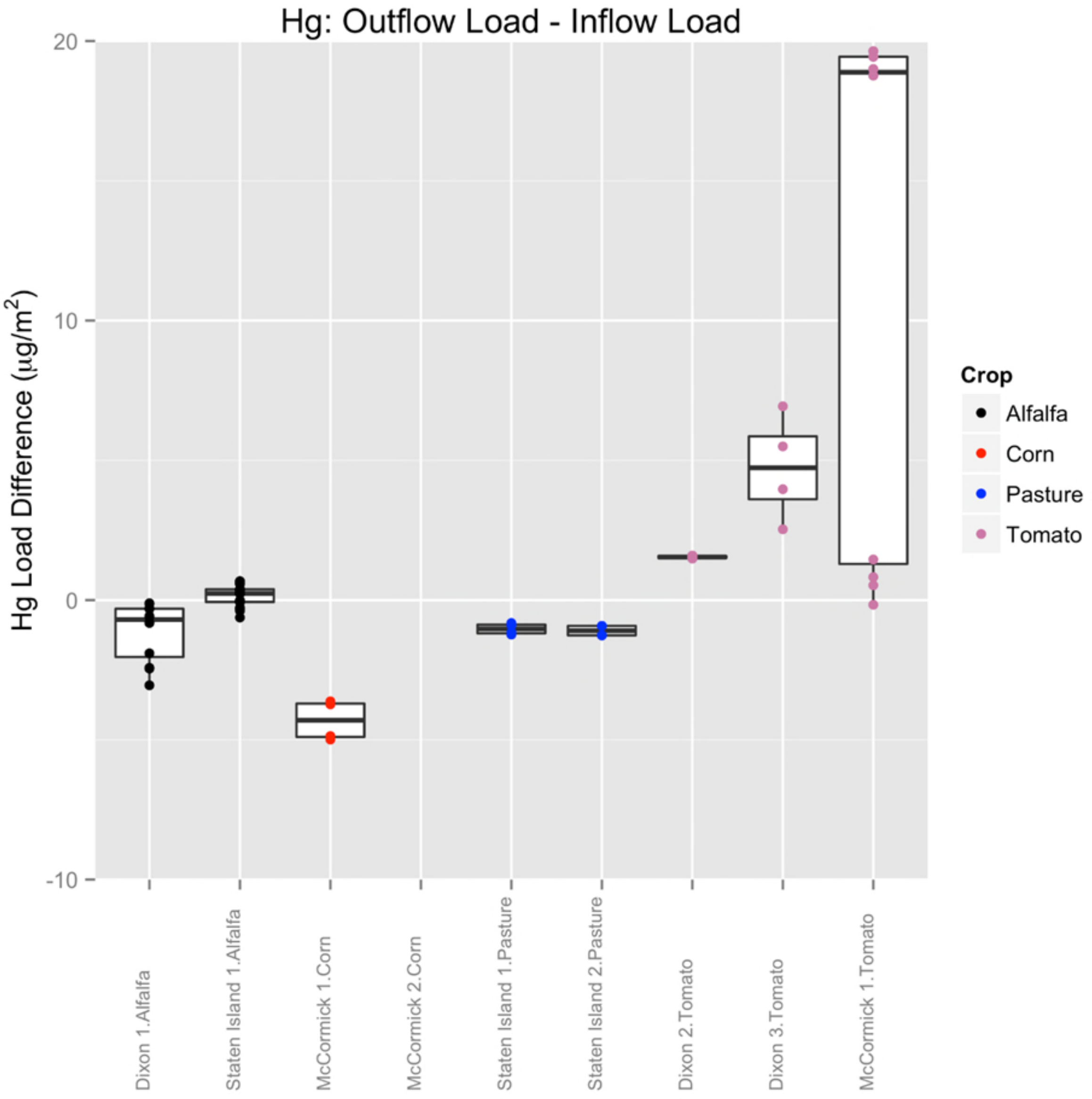


Figure 4-50 Load estimate (net load) for total Hg, runoff = 25% of water application, percolation = 5-25% of water application.

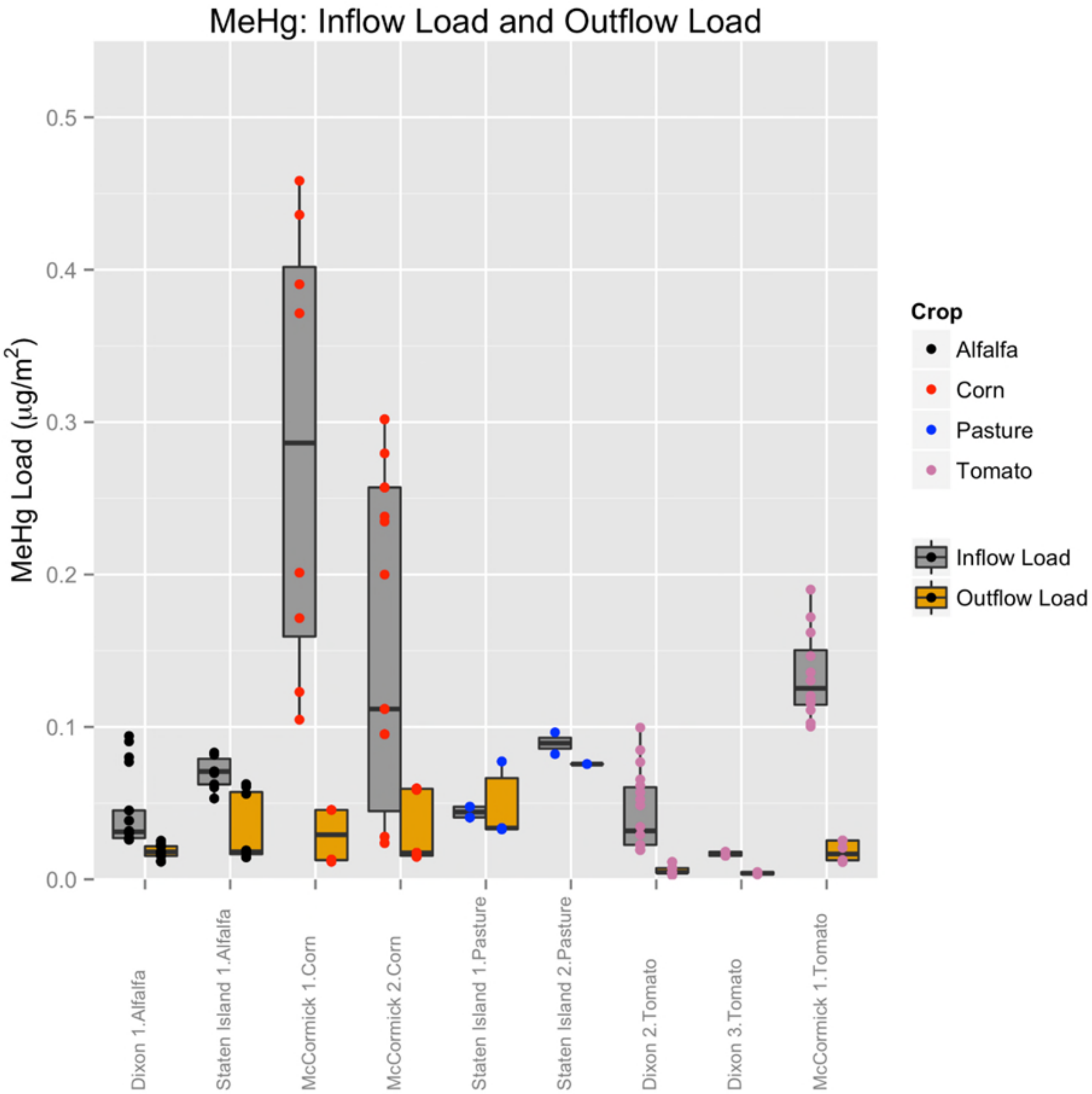


Figure 4-51 Load estimate (inflow and outflow load) for MeHg, runoff = 10% of water application, percolation = 5-25% of water application.

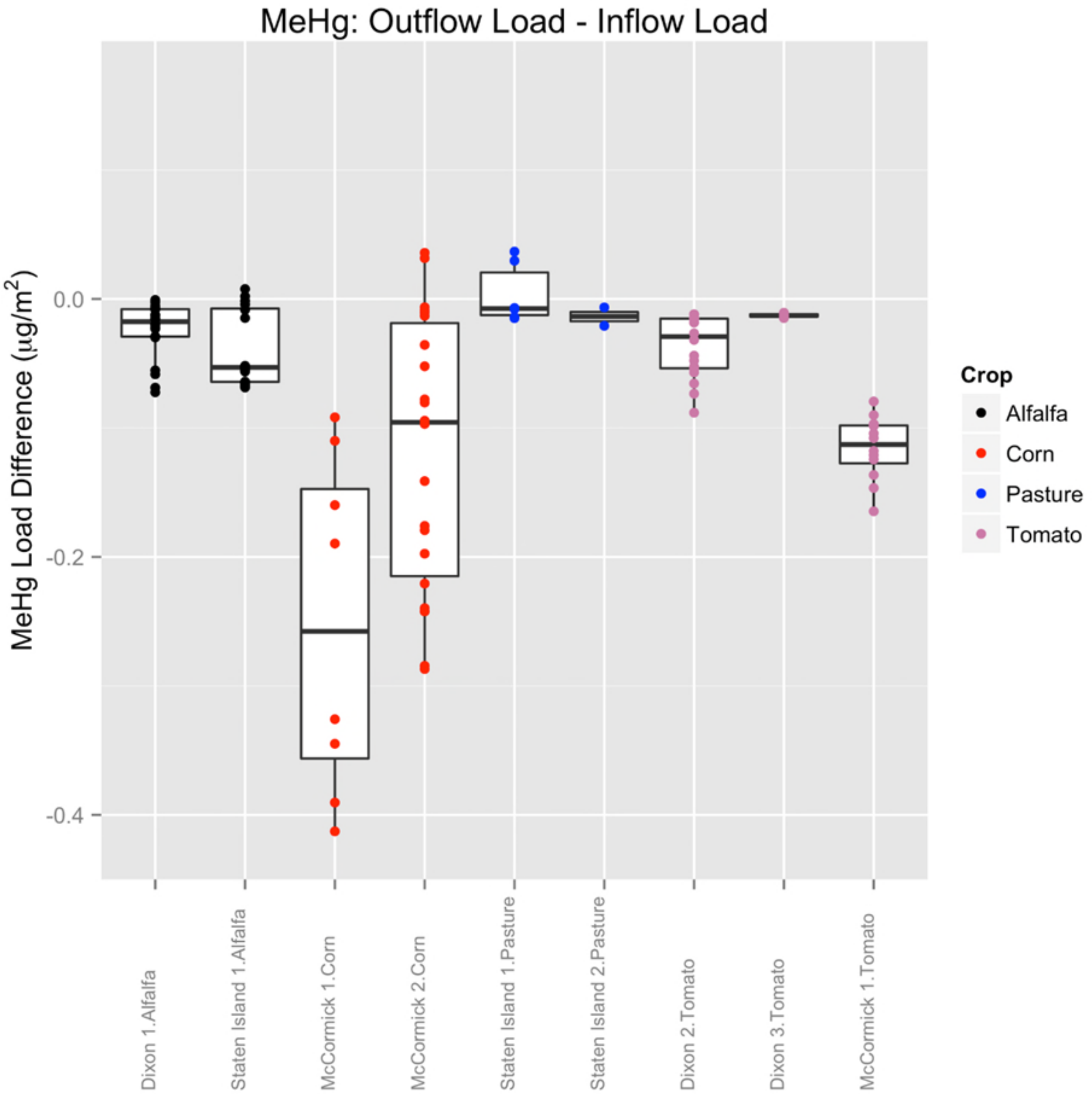


Figure 4-52 Load estimate (net load) for MeHg, runoff = 10% of water application, percolation = 5-25% of water application.

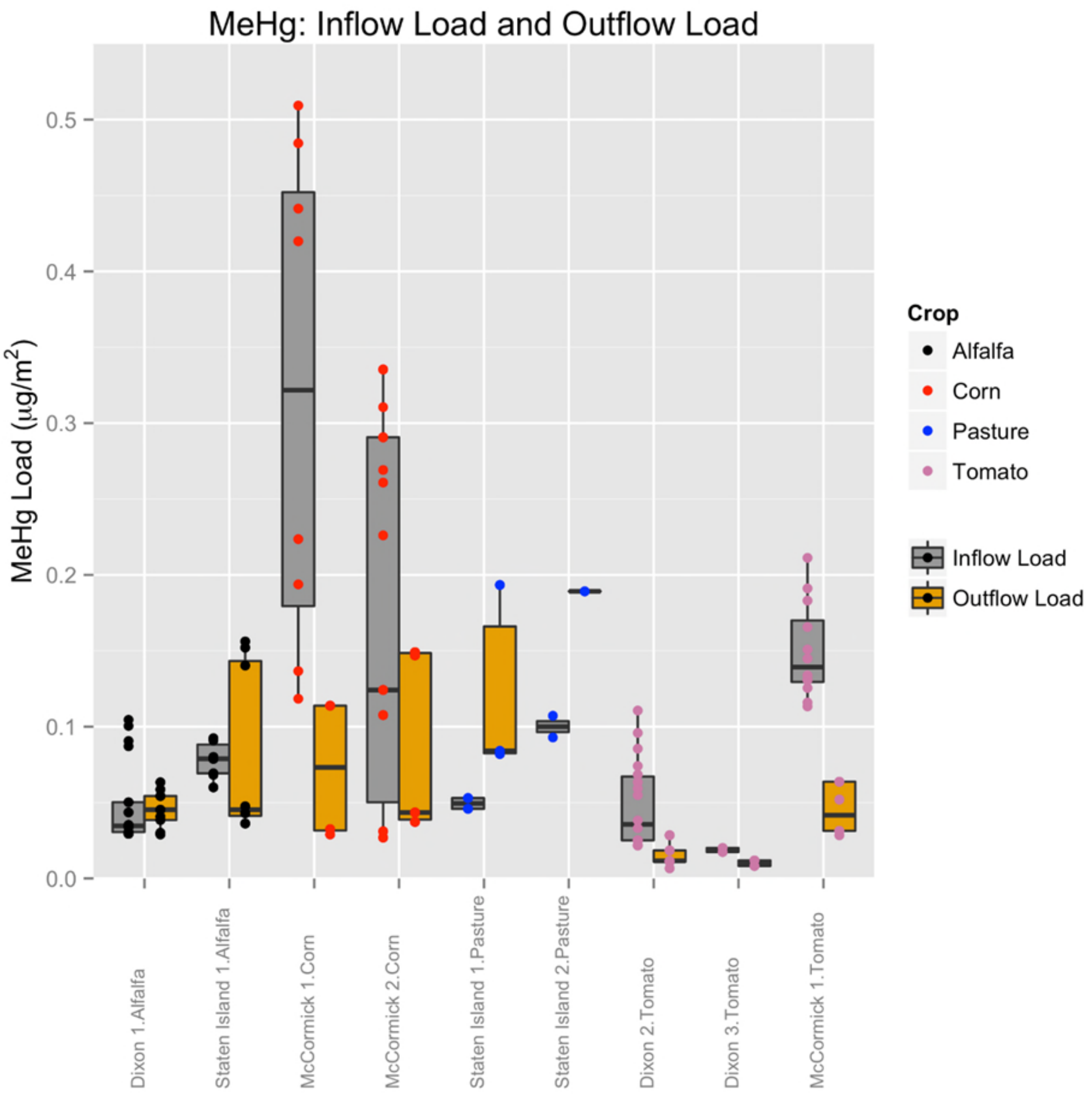


Figure 4-53 Load estimate (inflow and outflow load) for MeHg, runoff = 25% of water application, percolation = 5-25% of water application.

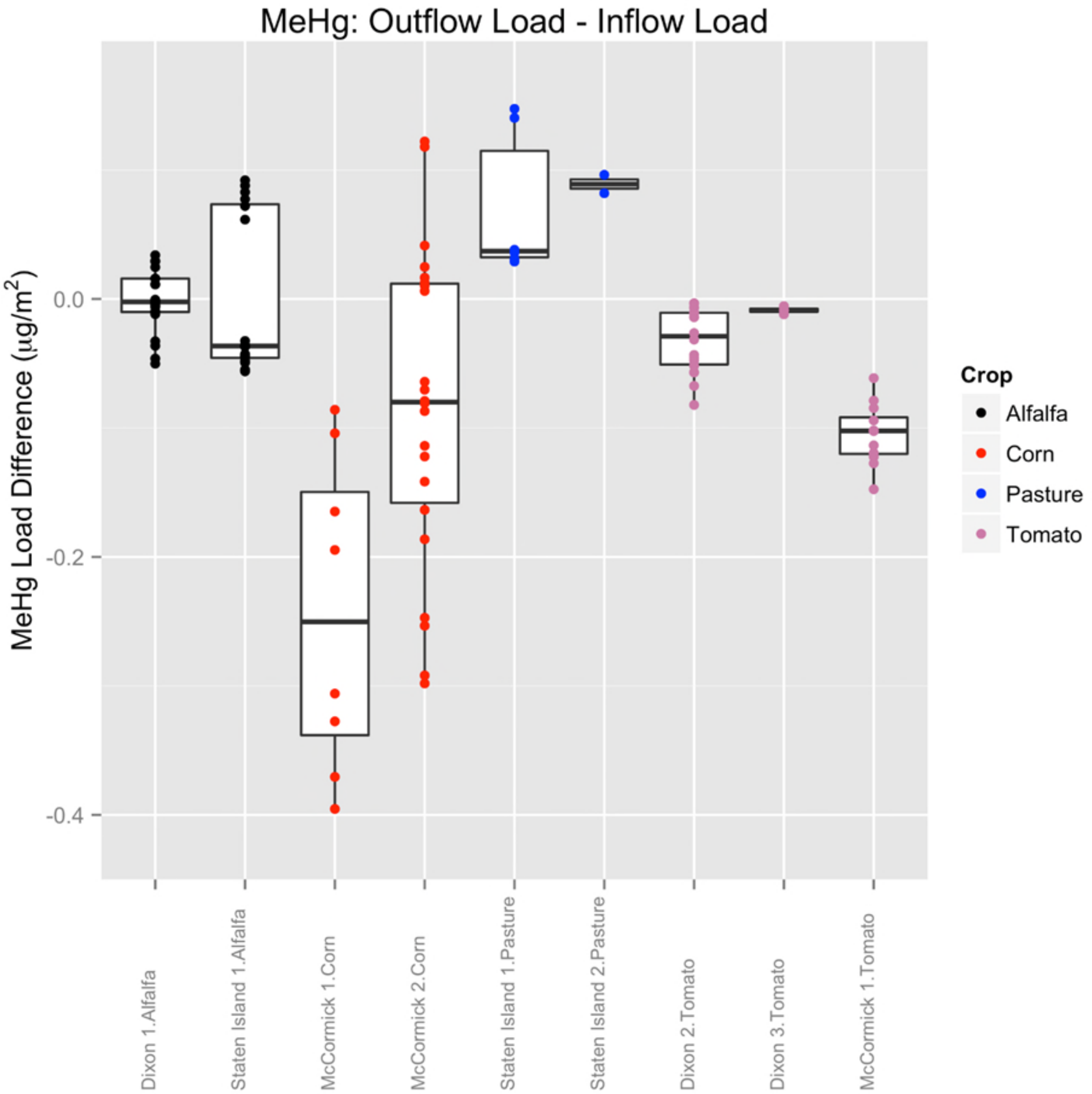


Figure 4-54 Load estimate (net load) for MeHg, runoff = 25% of water application, percolation = 5-25% of water application.

5 DISCUSSION AND NEXT STEPS

The present study was intended as a field investigation, where a combination of site types and crop types were sampled for mercury and related parameters, with the goal of inferring typical concentrations, effects on mercury species of water transport through the selected fields, and approximate estimates of exported loads, given assumptions on the irrigation water application. Given limitations of site access throughout the Delta, this study focused opportunistically on different crops and locations where access was possible. However, this was not a fully controlled study, in that the response of multiple crop types was not investigated for a given set of water and soil conditions, and changes that are observed from site to site may be a consequence of the crop, soils, inflows, and other farming practices, including water and fertilizer application, that could not be controlled for. Despite this caveat, however, this work adds considerably to the data and general understanding of mercury behavior in non-rice irrigated agriculture in the Delta and provides support for ongoing Phase 1 studies being performed, or being contemplated (CVRWQCB, 2012)). Some key findings from an evaluation of these data are presented below, and directions for future work that may be developed for the Delta mercury TMDL.

Key Points:

- It is clear from the data that there is MeHg production in fields, because the concentrations are much higher than would be predicted by evapoconcentration of water alone. MeHg concentration elevation is strongly correlated to DOC elevation in field outflows, and could be tied to an added transport pathway on DOC or to the stimulation of methylation due to the presence of DOC.

- Total Hg concentrations are elevated in the outflows, and this process is correlated well with increased TSS levels in outflows.

- Fields are sinks for MeHg and total Hg during summer because of field hydrology, i.e., the outflow volumes are much smaller than the inflow volumes. There is some potential for remobilization in winter, where the concentrations of MeHg and total

Hg are elevated, and the inflow loads can be considered to be near zero (i.e., only from Hg and MeHg in precipitation). However, in this study there were too few measurements following rain events to attempt a load estimation for winter.

- The runoff rates used here in the absence of observed data on hydrology are nonetheless considered to span a reasonable range, and the calculation of mostly negative export for both Hg and MeHg in the summer season is considered credible. The total water application rates (obtained by adding ET, runoff and percolation, the latter two quantities assumed at reasonable levels) are consistent with large scale irrigation water application in California.

- Drains are integrators across multiple fields and looking at a single field or crop on an island provides only very preliminary and incomplete data. They were not used for a quantitative analysis in this work, although the concentrations indicate lower values than the outflow locations, suggesting the presence of significant removal and settling mechanisms in the drains. For MeHg and total mercury it could be in form of particulate settling or volatilization, for MeHg it could be demethylation.

Next Steps

- Additional mercury data collection for another irrigation season or from additional fields could provide validation of the present findings.

- Data collection in winter could provide a more complete evaluation of the annual loads from fields, as opposed to loads from the dry season alone. Assuming MeHg in outflows in winter are similar to what was found in the dry or irrigation season, these would be a net positive export because the inflows in winter are considered to be zero.

- Hydrologic and mercury data collected in other Delta locations in related studies could be integrated to develop a more robust estimate of the loads from Delta agriculture in general.

- There is a need for more hydrologic data in these systems to provide greater confidence in the mercury loads. Studies may focus on islands with information on hydrology (and not necessarily mercury) that could provide greater information on water use efficiency that could incorporated in the water balances utilized here.

6 REFERENCES

Alpers CN, Fleck JA, Marvin-DiPasquale M, Stricker C, Stephenson M, Taylor HE. Mercury cycling in agricultural and managed wetlands, Yolo Bypass, California: Spatial and seasonal variations in water quality. Sci Total Environ 2014; 484:276–87.

Bachand PAM, Bachand SM, Fleck JA, Anderson F, Windham-Myers L. Differentiating transpiration from evaporation in seasonal agricultural wetlands and the link to advective fluxes in the root zone. Sci Total Environ 2014; 484:232–48.

Central Valley Regional Water Quality Control Board (CVRWQCB) (2010) Delta Methylmercury Staff Report.

CVRWQCB (2011) Amendments to the Water Quality Control Plan for the Sacramento River and San Joaquin River Basins for the Control of Methylmercury and Total Mercury in the Sacramento-San Joaquin River Delta Estuary

CVRWQCB (2012) Methylmercury Control Study Guidance for the Delta Methylmercury Control Program Implementation Phase I

Cooley, H. (2015) California Agricultural Water Use: Key Background information, Pacific Institute Report.

Heim, W.A., S. Deverel, T. Ingrum, W. Piekarski, and M. Stephenson (2009) Assessment of Methylmercury Contributions from Sacramento-San Joaquin Delta Farmed Islands. Final Report prepared for Central Valley Regional Water Quality Control Board.

Medellin-Azuara, J. and R. Howitt (2013) Comparing Consumptive Agricultural Water Use in the Sacramento-San Joaquin Delta, UC Davis Center for Watershed Sciences

Windham-Myers L, Ackerman JT, Fleck JA, Marvin-DiPasquale M, Stricker CA, Bachand P, Eagles-Smith CA, Feliz D, Gill G, Stephenson M, Alpers CN. 2014 Mercury cycling in agricultural and managed wetlands: A synthesis of methylmercury production, hydrologic export, and bioaccumulation from an integrated field study. Sci Total Environ 484:221–31.

Appendix A

Table A-1
Field data for pH, DO, temperature, EC, and Turbidity.

Site ID	Date/Time	Coordinates	Comments	pH	DO (mg/L)	Temp (°C)	EC (µS/cm^2)	Turbidity (NTU)
D1-SWA-1	6/9/2014 10:30am	N: 38°25'26.8" W: 121°52'07.9"	Clear, windy, warm, sunny	8.68	13.67	18.07	390	30.6
D1-TWA-1A D1-TWA-1B	6/9/2014 11:10am	Confidential	Clear, windy, warm, sunny	7.59	8.05	25.22	432	25.2
D1-DCA-1	6/9/2014 12:00pm	N: 38°25'01.1" W: 121°52'24.5"	Clear, windy, warm, sunny	7.76	6.56	24.05	410	94.1
D2-TWT-1	6/10/2014 11:30am	Confidential	Clear, warm, sunny	8.08	0.38	33.6	297	353.1
D2-DCT-1	6/10/2014 12:14pm	N: 38°25'57.1" W: 121°56'03.6"	Clear, warm, sunny	8.16	0.55	29.83	758	7.1
D2-SWT-1	6/10/2014 1:00pm	N: 38°25'31.5" W: 121°56'01.1"	Clear, warm, sunny	8.41	4.63	15.66	354	4.9
M1-SWMC-1	6/23/2014 10:35am	N: 38°15'11.1" W: 121°28'49.4"	Slight turbid water, Clear, warm, slight breeze	9	11.63	24.93	144	74.5
M1-TWC-1	6/23/2014 11:08am	N: 38°15'9.7" W: 121°29'4.4"	Slight turbid water, Clear, warm, slight breeze	7.59	8.42	29.62	140	1052.52
M1-SW-1A M1-SW-1B	6/23/2014 11:56am	N: 38°15'37.8" W: 121°27'59.8"	Clear, warm, slight breeze	9.01	10.04	23.8	127	18.4
M1-TWT-1	6/23/2014 12:30pm	N: 38°15'45.2" W: 121°28'00.2"	Slight turbid water, Clear, warm, slight breeze	8.61	8.04	32.42	155	190
S1-SWA-1	6/30/2014 10:05am	N: 38.226968° W: 121.499318°	Clear, Very hot	6.9	7.7	23.2	138	N/A
S1-TWA-1	6/30/2014 11:15am	N: 38.221211° W: 121.499318°	Clear, Very hot	6.32	6.5	37.7	192	N/A
S1-DCAP-1	6/30/2014 12:30pm	N: 38.192618° W: 121.528203°	Clear, Very hot	7.0	4.3	27.6	258	N/A
S2-SWP-1	6/30/2014 13:40pm	N: 38.196623° W: 121.506399°	Clear, Very hot	7.22	7.6	24.0	135	N/A
S2-TWP-1	6/30/2014 14:25pm	N: 38.1332° W: 121.533524°	Clear, Very hot	6.98	1.0	35.9	210	N/A

Site ID	Date/Time	Coordinates	Comments	pH	DO (mg/L)	Temp (°C)	EC (µS/cm²)	Turbidity (NTU)
D1B-TWA-1	7/8/2014 11:42am	Confidential	Overcast, warm, breezy	7.94	5.6	28.9	428	2.8
D1B-DCA-1	7/8/2014 12:10pm	N: 38°25'01.0" W: 121°52'23.7"	Overcast, warm, breezy	7.95	5.4	23.13	434	23.1
D1B-SWA-1	7/8/2014 12:40pm	N: 38°25'26.5" W: 121°52'07.9"	Overcast, warm, breezy	8.61	8.65	18.09	388	2.2
D2B-SWT-1A D2B-SWT-1B	7/8/2014 1:20pm	N: 38°21'31.5" W: 121°56'01.2"	Overcast, warm, breezy	8.33	7.5	15.77	374	2.7
D2B-TWT-1	7/8/2014 1:50pm	Confidential	Overcast, warm, breezy	8.44	4.42	32.7	416	91.2
M-DC-1	7/14/2014 12:30pm	N: 38.23595° W: 121.48809°	Hot, clear, sunny	6.99	6.76	27	214	N/A
M2-TWC-1	7/14/2014 13:30pm	N: 38.25652° W: 121.48448°	Hot, clear, sunny	6.34	0.81	28.33	165	N/A
M2-SWC-1 M2-SWC-	7/14/2014 13:45pm	N: 38.25624° W: 121.47733°	Hot, clear, sunny	7.13	6.01	28.92	155	N/A
M1-TWT-1	7/14/2014 14:10pm	N: 38.26262° W: 121.46674°	Hot, clear, sunny	7.32	4.78	35.03	174	N/A
M1-SWT-1	7/14/2014 14:40pm	N: 38.26057° W: 121.466661°	Hot, clear, sunny	7.59	8.93	25.59	149	N/A
S-TWP-1	8/4/2014 10:30am	N: 38.20043° W: 121.57603°	Overcast, warm	6.57	4.04	21.85	337	N/A
S2-SWP-2 S2-SWP-2D	8/4/2014 10:50am	N: 38.19958° W: 121.52316°	Overcast, warm	7.13	6.62	23.97	163	N/A
S1-DCAP-2	8/4/2014 11:30am	N: 38.13366° W: 121.53539°	Overcast, warm	6.70	7.02	21.95	442	N/A
S1-SWA-2	8/4/2014 12:10pm	N: 38.22693° W: 121.49300°	Overcast, warm	6.79	7.04	23.89	165	N/A
S-TWA-2	8/4/2014 12:40pm	N: 38°13’38” W: 121°29’29”	Overcast, warm	6.48	2.45	24.84	189	N/A
D1C-TWA-1A D1C-TWA-1B	8/5/2014 10:45am	Confidential	Cloudy, sprinkles	7.41	2.96	20.45	402	4.1

Site ID	Date/Time	Coordinates	Comments	pH	DO (mg/L)	Temp (°C)	EC (µS/cm²)	Turbidity (NTU)
D1C-DCA-1	8/5/2014 11:00am	N: 38°25'01.0" W: 121°52'24.6"	Cloudy, light rain, slightly turbid	7.59	4.12	20.44	401	8.2
D1C-SWA-1	8/5/2014 11:45am	N: 38°25'26.5" W: 121°52'08.0"	Cloudy, clear water	8	8.7	16.03	325	1.8
D2C-TWT-1	8/5/2014 12:15pm	Confidential	Cloudy, slightly turbid	8.26	6.53	21.4	356	12.5
D2C-SWT-1	8/5/2014 12:30pm	N: 38°21'31.5" W: 121°56'01.0"	Cloudy, clear water	8.5	9.57	14.89	294	0.4
M-TWT-3	8/14/2014 10:30am	N: 38.25844° W: 121.47678°	Sunny, clear	8.29	8.95	26.9	164	N/A
M-SWMT	8/14/2014 11:35am	N: 38.25885° W: 121.47495°	Sunny, clear	8.29	10.57	24.8	154	N/A
M-TWC	8/14/2014 12:30pm	N: 38.25549° W: 121.48444°	Sunny, clear	7.4	9.00	21.12	161	N/A
M-SWMC M-SWMC-D	8/14/2014 12:55pm	N: 38.25542° W: 121.47831°	Sunny, clear	8.85	8.94	29.01	157	N/A
M5SWC1082514	8/25/2014 10:57am	N: 38°15'11.1" W: 121°28'49.4"	Breezy, sunny, clear	6.69	8.10	23.1	166	N/A
M5TWC1082514 M5TWC2082514	8/25/2014 11:54am	N: 38°15'9.7" W: 121°29'4.4"	Breezy, sunny, clear	7.39	9.19	22.8	205	N/A
M6SWRC1 082514	8/25/2014 1:08pm	N: 38.25652° W: 121.48448°	Breezy, sunny, clear	7.10	10.82	22.92	241	N/A
M6TWC1082514	8/25/2014 1:30pm	N: 38.25624° W: 121.47733°	Breezy, sunny, clear	7.03	6.79	22.13	316	N/A
S-TWA-3 S-TWA-3D	9/2/2014 10:20am	Confidential	Sunny, slight breeze	6.88	2.38	23.04	221	N/A
S-SWA-MC	9/2/2014 11:00am	N: 38.22531° W: 121.49279°	Sunny, slight breeze	7.21	6.34	23.37	188	N/A
S1-SWA-3	9/2/2014 11:20am	N: 38.22697° W: 121.49310°	Sunny, slight breeze	7.31	6.71	23.37	190	N/A
S1-DCAP-3	9/2/2014 11:50am	N: 38.13367° W: 121.53537°	Sunny, slight breeze	7.67	12.5	24.39	839	N/A

Site ID	Date/Time	Coordinates	Comments	pH	DO (mg/L)	Temp (°C)	EC (µS/cm²)	Turbidity (NTU)
S-SWP-3	9/2/2014 12:45pm	N: 38.19970° W: 121.52319°	Sunny, slight breeze	7.49	8.27	24.53	189	N/A
D3A-SWT-1	9/3/2014 11:49am	N: 38°26'18.7" W: 121°51'01.5"	Clear, warm, Water is flowing fast	7.23	4.13	19.94	672	6.3
D3A-TWT-1A D3A-TWT-1B	9/3/2014 12:15pm	Confidential	Clear, warm, slight breeze Turbid water	7.96	4.04	31.73	704	780
D3A-DCT-1	9/3/2014 12:34pm	N: 38°26'05.8" W: 121°51'18.1"	Clear, warm, slight breeze Turbid water	8.11	4.19	30.98	699	513
D1D-SWA-1A D1D-SWA-1B	9/10/2014 11:55am	N: 38°25'26.7" W: 121°52'0.8"	Clear, warm, slight breeze Clear, fast flowing water	8.55	11.58	21.08	385	7.7
D1D-TWA-1	9/10/2014 12:25pm	Confidential	Clear, warm, breezy	7.7	4.51	27.31	414	1.8
D1D-DCA-1	9/10/2014 12:45pm	N: 38°25'01.1" W: 121°52'24.5"	Clear, warm, breezy, turbid water	7.98	7.1	20.67	367	12.6
SPTW100214A SPTW100214B	10/2/2014 9:50am	N: 38.20111° W: 121.51605°	Clear, sunny	6.66	7.6	16.8	179	N/A
SPTW2100214	10/2/2014 10:50am	N: 38.191257° W: 121.50797°	Clear, sunny	6.72	6.08	19.19	234	N/A
SPSW2100214	10/2/2014 11:30am	N: 38.192618° W: 121.5282°	Clear, sunny	6.99	6.3	20.34	150	N/A
SPMD100214	10/2/2014 12:45pm	N: 38.13320° W: 121.53352°	Clear, sunny	7.37	6.41	16.97	781	N/A
D1E-TW (storm sampling)	12/3/2014 11:30am	Confidential	Windy, Rain	7.31	8.91	15.16	174	408.1
D1E-DC-1A D1E-DC-1B (storm sampling)	12/3/2014 11:45am	N: 38°25'01.1" W: 121°52'24.5"	Windy, Rain	7.18	8.46	13.77	211	377.5

Site ID	Date/Time	Coordinates	Comments	pH	DO (mg/L)	Temp (°C)	EC (µS/cm²)	Turbidity (NTU)
D2E-TW (storm sampling)	12/3/2014 12:30pm	Confidential	Windy, Rain	7.44	10.97	14.75	458	149.5
D1F-TW (storm sampling)	12/12/2014 11:00am	Confidential	Windy, Rain	6.91	9.53	12.27	244	87.8
D1F-DC-1A D1F-DC-1B (storm sampling)	12/12/2014 11:15am	N: 38°25'01.1" W: 121°52'24.5"	Windy, Rain	6.71	10.37	11.17	102	127.2
D2F-TW (storm sampling)	12/12/2014 12:30pm	Confidential	Windy, Rain	6.85	10.99	11.92	120	183.1
S3ATW121714	12/17/2014 1:10pm	N: 38.219078° W: 121.501212°	Cloudy, light rain	6.11	N/A	N/A	N/A	N/A
S4PTW121714	12/17/2014 2:00pm	N: 38.201059° W: 121.516058°	Cloudy, light rain	6.47	N/A	N/A	N/A	N/A
S6MDmid121714	12/17/2014 2:30pm	N: 38.18556° W: 121.50881°	Cloudy, light rain	6.68	N/A	N/A	N/A	N/A
S8PTW121714	12/17/2014 2:45pm	N: 38.20151° W: 121.504996°	Cloudy, light rain	6.49	N/A	N/A	N/A	N/A
S8PTW020915	2/9/2015 9:16am	N: 38.20111° W: 121.50512°	Warm, Sunny	6.64	8.30	13.17	216	N/A
S9PTW020915	2/9/2015 9:54am	N: 38.20250° W: 121.50752°	Warm, Sunny	6.88	11.74	15.6	217	N/A
SMD-mid020915	2/9/2015 10:35am	N: 38.18556° W: 121.50881°	Warm, Sunny	7.00	4.25	13.82	1057	N/A
S1SWP020915	2/9/2015 11:15am	N: 38.19262° W: 121.52820°	Warm, Sunny	6.88	9.21	12.45	127	N/A

Table A-2
Laboratory data for total and methylmercury.

Sample ID	Inflow	Outflow	Drain	Crop Type	Wet/Dry Period	Site	Date Collected	EPA MeHg, ng/l	MLML, MeHg, ng/l	MLML, Total Hg, ng/l
D1-SWA-1	X			Alfalfa	Dry	Dixon 1	6/9/2014	0.037	0.026	
D1-TWA-1A		X		Alfalfa	Dry	Dixon 1	6/9/2014	0.18	0.128	
D1-TWA-1B		X		Alfalfa	Dry	Dixon 1	6/9/2014	0.17	0.133	
D1-DCA-1			X	Alfalfa	Dry	Dixon 1	6/9/2014	0.43	0.305	
D1-FB				Alfalfa	Dry	Dixon 1	6/9/2014	ND	ND	
D2-TWT-1		X		Tomato	Dry	Dixon 2	6/10/2014	0.17	0.069	
D2-SWT-1	X			Tomato	Dry	Dixon 2	6/10/2014	0.085	0.063	0.987
D2-SWT-1B	X			Tomato	Dry	Dixon 2	6/10/2014	0.11	0.068	
D2-DCT-A			X	Tomato	Dry	Dixon 2	6/10/2014	0.26	0.186	1.75
M1-SWMC-1	X			Corn	Dry	McCormick 1	6/23/2014	0.18	0.11	
M1-TWC-1		X		Corn	Dry	McCormick 1	6/23/2014	0.14	0.157	500
M1-SW-1A	X			Tomato	Dry	McCormick 1	6/23/2014	0.19	0.144	4.78
M1-SW-1B	X			Tomato	Dry	McCormick 1	6/23/2014	0.21	0.133	5.01
FB-1M				Tomato	Dry	McCormick 1	6/23/2014	ND	ND	ND
M1-TWT-1		X		Tomato	Dry	McCormick 1	6/23/2014	0.38	0.187	142.0
S1-SWA-1(B)	X			Alfalfa	Dry	Staten Island 1	6/30/2014	0.058	0.051	1.6
S1-TWA-1(B)		X		Alfalfa	Dry	Staten Island 1	6/30/2014	0.69	0.672	11.3
S1-DCAP-1			X	Alfalfa	Dry	Staten Island 1	6/30/2014	0.11		4.0
S2-SWP-1	X			Pasture	Dry	Staten Island 2	6/30/2014	0.085		2.0
S2-TWP-1		X		Pasture	Dry	Staten Island 2	6/30/2014	0.9		6.0
S2-FBP-1				Pasture	Dry	Staten Island 2	6/30/2014	ND		ND
S1-TWA-1DUP		X		Alfalfa	Dry	Staten Island 1	6/30/2014	0.62		10.9
D1B-TWA-1		X		Alfalfa	Dry	Dixon 1	7/8/2014	0.28	0.259	4.2
D1B-DCA-1			X	Alfalfa	Dry	Dixon 1	7/8/2014	0.22	0.216	5.2
D1B-SWA-1	X			Alfalfa	Dry	Dixon 1	7/8/2014	ND	ND	1.3
D2B-SWT-1A	X			Tomato	Dry	Dixon 2	7/8/2014	ND	ND	0.62

Sample ID	Inflow	Outflow	Drain	Crop Type	Wet/Dry Period	Site	Date Collected	EPA MeHg, ng/l	MLML, MeHg, ng/l	MLML, Total Hg, ng/l
D2B-SWT-1B	X			Tomato	Dry	Dixon 2	7/8/2014	ND	ND	0.60
D2B-TWT-1		X		Tomato	Dry	Dixon 2	7/8/2014	0.11	0.066	12.6
M-DC-1			X	Corn	Dry	McCormick 1	7/14/2014	0.47		15.8
M2-TWC		X		Corn	Dry	McCormick 2	7/14/2014	0.71		846.0
M2-SWC	X			Corn	Dry	McCormick 2	7/14/2014	0.25		11.7
M2-SWC-DUP	X			Corn	Dry	McCormick 2	7/14/2014	0.21		12.9
M1-TWT		X		Tomato	Dry	McCormick 1	7/14/2014	0.31		33.1
M1-SWT	X			Tomato	Dry	McCormick 1	7/14/2014	0.13		4.7
S-TWP-1		X		Pasture	Dry	Staten Island 1	8/4/2014	3.6		19.4
S2-SWP-2	X			Pasture	Dry	Staten Island 2	8/4/2014	0.079		1.2
S2-SWP-2D	X			Pasture	Dry	Staten Island 2	8/4/2014	0.059		1.1
S1-DCAP-2			X	Alfalfa	Dry	Staten Island 1	8/4/2014	0.19		2.8
S1-SWA-2	X			Alfalfa	Dry	Staten Island 1	8/4/2014	0.068		1.6
S-TWA-2		X		Alfalfa	Dry	Staten Island 1	8/4/2014	0.21		9.4
D1C-TWA-1A		X		Alfalfa	Dry	Dixon 1	8/5/2014	0.2		4.6
D1C-TWA-1B		X		Alfalfa	Dry	Dixon 1	8/5/2014	0.2		4.7
D1C-DCA-1			X	Alfalfa	Dry	Dixon 1	8/5/2014	0.2		3.3
D1C-SWA-1	X			Alfalfa	Dry	Dixon 1	8/5/2014	ND		1.0
D2C-TWT-1		X		Tomato	Dry	Dixon 2	8/5/2014	0.04		3.9
D2C-SWT-1	X			Tomato	Dry	Dixon 2	8/5/2014	0.038		NA
M-TWT-3		X		Tomato	Dry	McCormick 1	8/14/2014	0.17		30.2
M-FB				Tomato	Dry	McCormick 1	8/14/2014	ND		ND
M-SWMT	X			Tomato	Dry	McCormick 1	8/14/2014	0.15		5.2
M-TWC		X		Corn	Dry	McCormick 1	8/14/2014	0.55		21.5
M-SWMC	X			Corn	Dry	McCormick 1	8/14/2014	0.41		7.5
M-SWMC-D	X			Corn	Dry	McCormick 1	8/14/2014	0.39		7.6
M5SWC1-082514	X			Corn	Dry	McCormick 2	8/25/2014	0.10		
M5SWCFB-082514	X			Corn	Dry	McCormick 2	8/25/2014	ND		

Sample ID	Inflow	Outflow	Drain	Crop Type	Wet/Dry Period	Site	Date Collected	EPA MeHg, ng/l	MLML, MeHg, ng/l	MLML, Total Hg, ng/l
M5TWC1-082514		X		Corn	Dry	McCormick 2	8/25/2014	0.21		
M5TWC2-082514		X		Corn	Dry	McCormick 2	8/25/2014	0.18		
M6SWRC1-082514	X			Corn	Dry	McCormick 2	8/25/2014	0.27		
M6TWC1-082514		X		Corn	Dry	McCormick 2	8/25/2014	0.72		
S-TWA-3		X		Alfalfa	Dry	Staten Island 1	9/2/2014	0.19		7.56
S-TWA-3D		X		Alfalfa	Dry	Staten Island 1	9/2/2014	0.16		8.61
S-SWA-MC	X			Alfalfa	Dry	Staten Island 1	9/2/2014	0.068		1.72
S1-SWA-3	X			Alfalfa	Dry	Staten Island 1	9/2/2014	0.067		1.46
S1-DCAP-3			X	Alfalfa	Dry	Staten Island 1	9/2/2014	0.22		2.87
S-SWP-3	X			Pasture	Dry	Staten Island 1	9/2/2014	0.063		1.23
D3A-SWT-1	X			Tomato	Dry	Dixon 3	9/3/2014	0.020		10.7
D3A-TWT-1A		X		Tomato	Dry	Dixon 3	9/3/2014	0.071		79.3
D3A-TWT-1B		X		Tomato	Dry	Dixon 3	9/3/2014	0.049		97
D3A-DCT-1			X	Tomato	Dry	Dixon 3	9/3/2014	0.071		86.9
D1D-SWA-1A	X			Alfalfa	Dry	Dixon 1	9/10/2014	0.074		3.46
D1D-SWA-1B	X			Alfalfa	Dry	Dixon 1	9/10/2014	0.077		3.02
D1D-TWA-1		X		Alfalfa	Dry	Dixon 1	9/10/2014	0.24		7.29
D1D-DCA-1			X	Alfalfa	Dry	Dixon 1	9/10/2014	0.25		3.65
SPTW100214A		X		Pasture	Dry	Staten Island 1	10/2/2014	0.39		6.1
SPTW100214B		X		Pasture	Dry	Staten Island 1	10/2/2014	0.40		6.33
SPTW2100214		X		Pasture	Dry	Staten Island 1	10/2/2014	0.92		5.94
SPSW2100214	X			Pasture	Dry	Staten Island 1	10/2/2014	0.042		1.97
SPMD100214			X	Pasture	Dry	Staten Island 1	10/2/2014	0.28		3.62
SPFB100214				Pasture	Dry	Staten Island 1	10/2/2014	ND		ND
D1E-TW		X		Alfalfa	Wet	Dixon 1	12/3/2014	0.37		101
D1E-DC-1A			X	Alfalfa	Wet	Dixon 1	12/3/2014	0.52		51.6
D1E-DC-1B			X	Alfalfa	Wet	Dixon 1	12/3/2014	0.40		49.5
D2E-TW		X		Tomato	Wet	Dixon 2	12/3/2014	0.069		17.6

Sample ID	Inflow	Outflow	Drain	Crop Type	Wet/Dry Period	Site	Date Collected	EPA MeHg, ng/l	MLML, MeHg, ng/l	MLML, Total Hg, ng/l
D1F-TW		X		Alfalfa	Wet	Dixon 1	12/12/2014	0.24		15.66
D1F-DC-1A			X	Alfalfa	Wet	Dixon 1	12/12/2014	0.16		16.4
D1F-DC-1B			X	Alfalfa	Wet	Dixon 1	12/12/2014	0.15		16.5
D2F-TW		X		Tomato	Wet	Dixon 2	12/12/2014	0.14		17.8
S3ATW121714		X		Alfalfa	Wet	Staten Island 2	12/17/2014	0.056		12.8
S4PTW121714		X		Pasture	Wet	Staten Island 2	12/17/2014	0.46		8.99
S6MD-mid121714			X	Pasture	Wet	Staten Island 2	12/17/2014	0.59		9.03
S8PTW121714		X		Pasture	Wet	Staten Island 2	12/17/2014	0.22		10.8
S8PTW020915		X		Pasture	Wet	Staten Island 2	2/9/2015	0.21		18.1
S9PTW020915		X		Pasture	Wet	Staten Island 2	2/9/2015	2.3		15.4
SMD-mid020915			X	Pasture	Wet	Staten Island 1	2/9/2015	0.35		7.65
S1SWP020915	X			Pasture	Wet	Staten Island 1	2/9/2015	0.085		1.49
S1FB020915				Pasture	Wet	Staten Island 1	2/9/2015	ND		ND

Appendix B

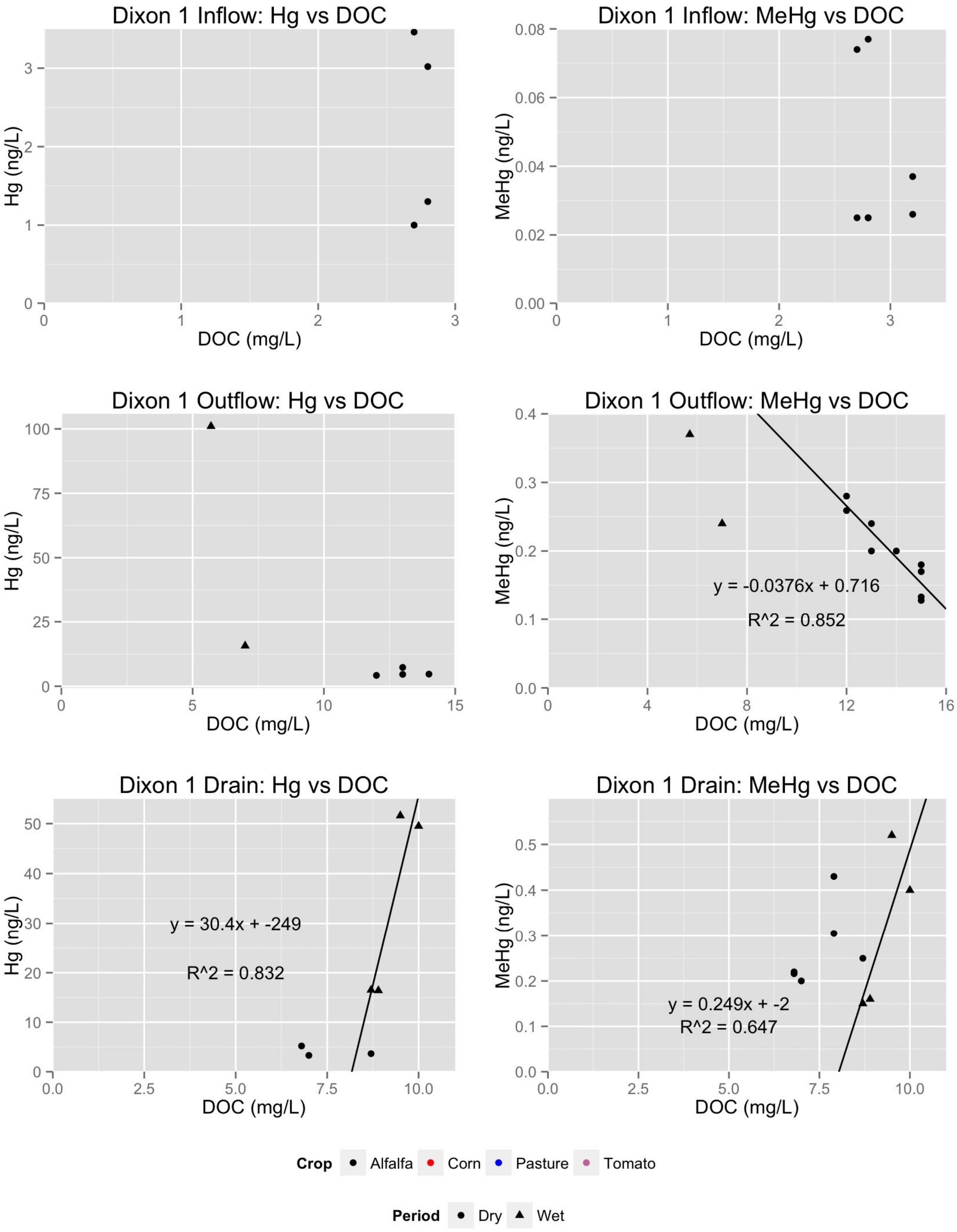


Figure B-1 Dixon 1 DOC relationships (alfalfa)

For the dry period, outflow MeHg concentration is seen to decrease with increasing DOC concentration, while for the wet season drain Hg and MeHg concentrations increase with increasing DOC concentration.

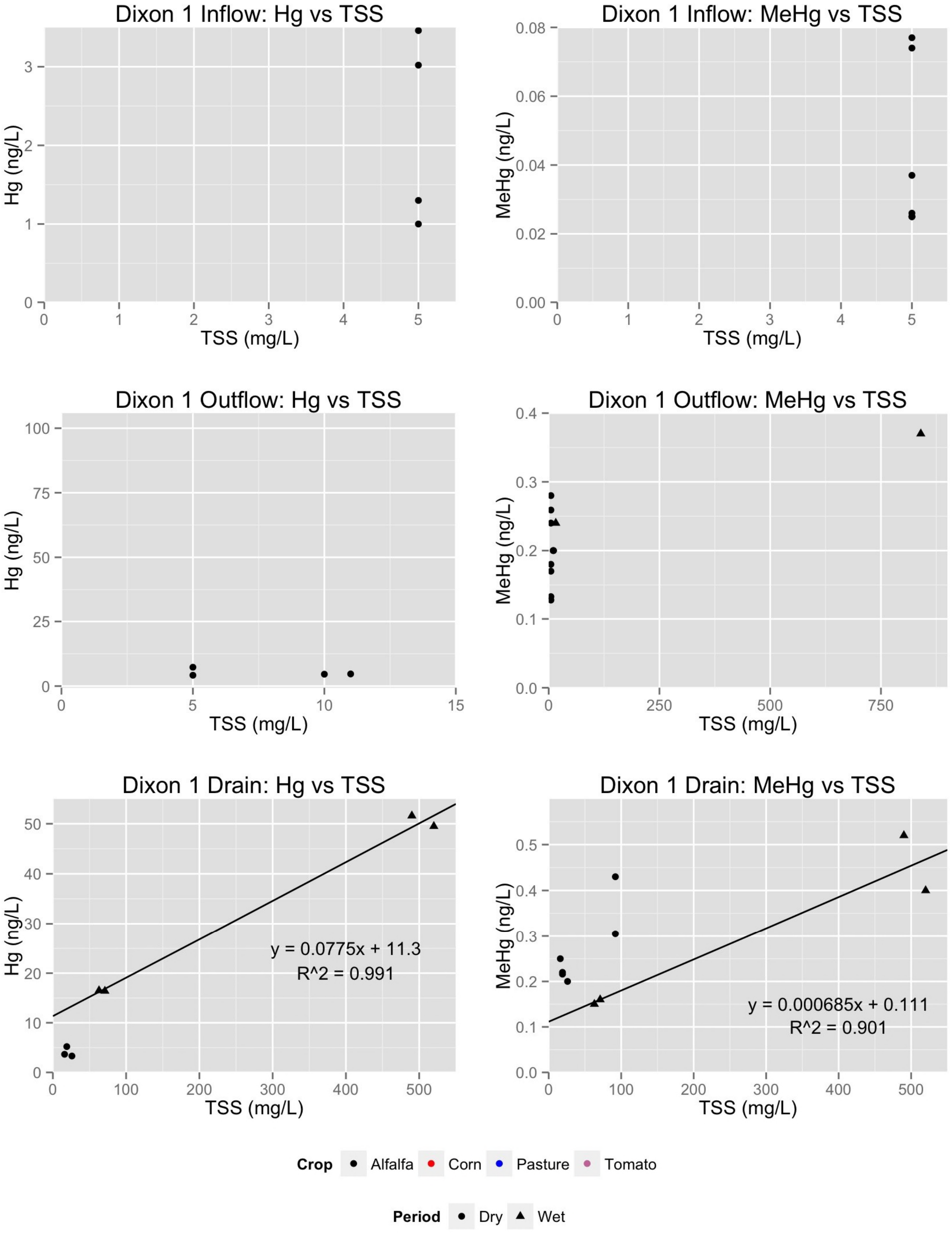


Figure B-2 Dixon 1 TSS relationships (alfalfa)

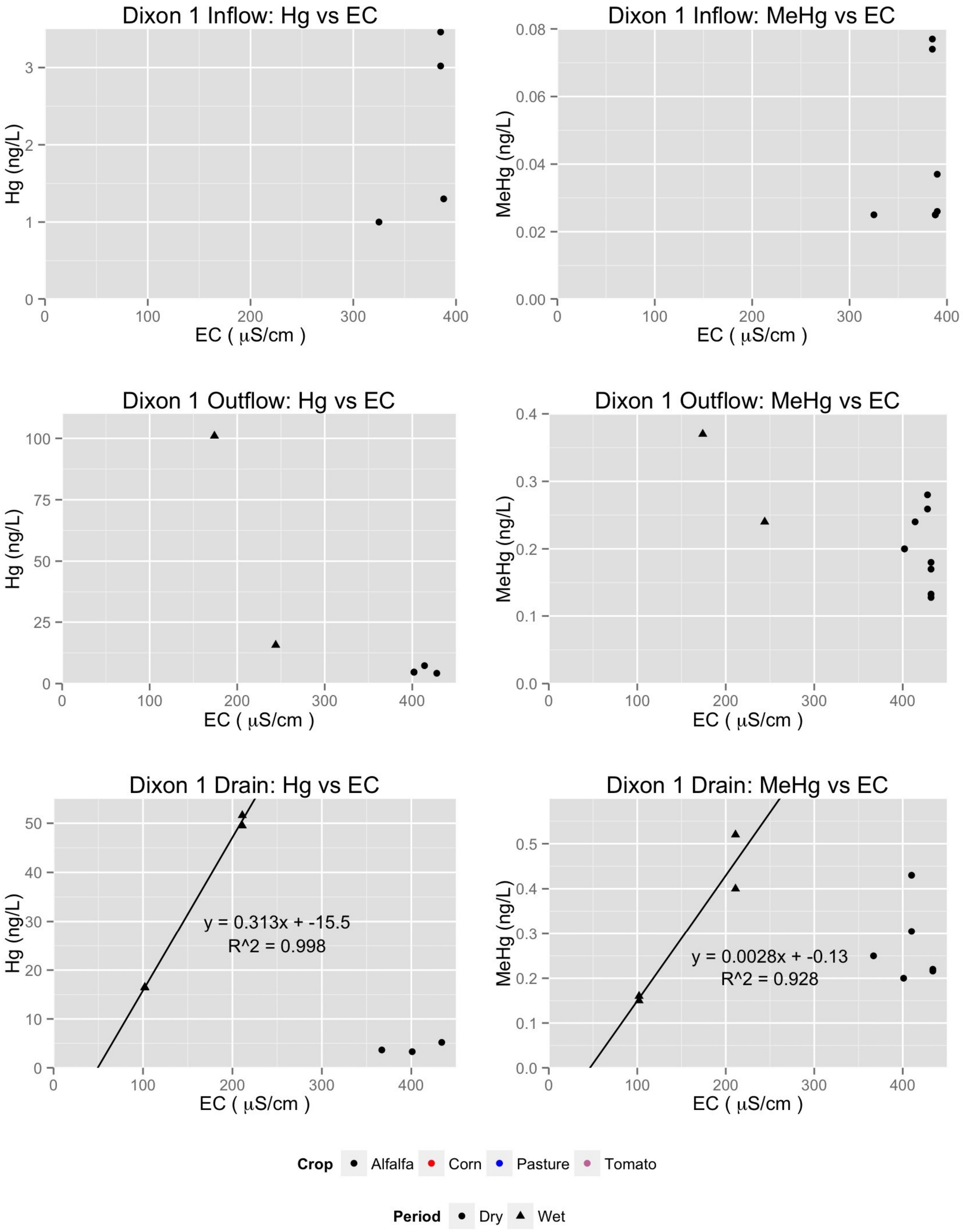


Figure B-3 Dixon 1 EC relationships (alfalfa)

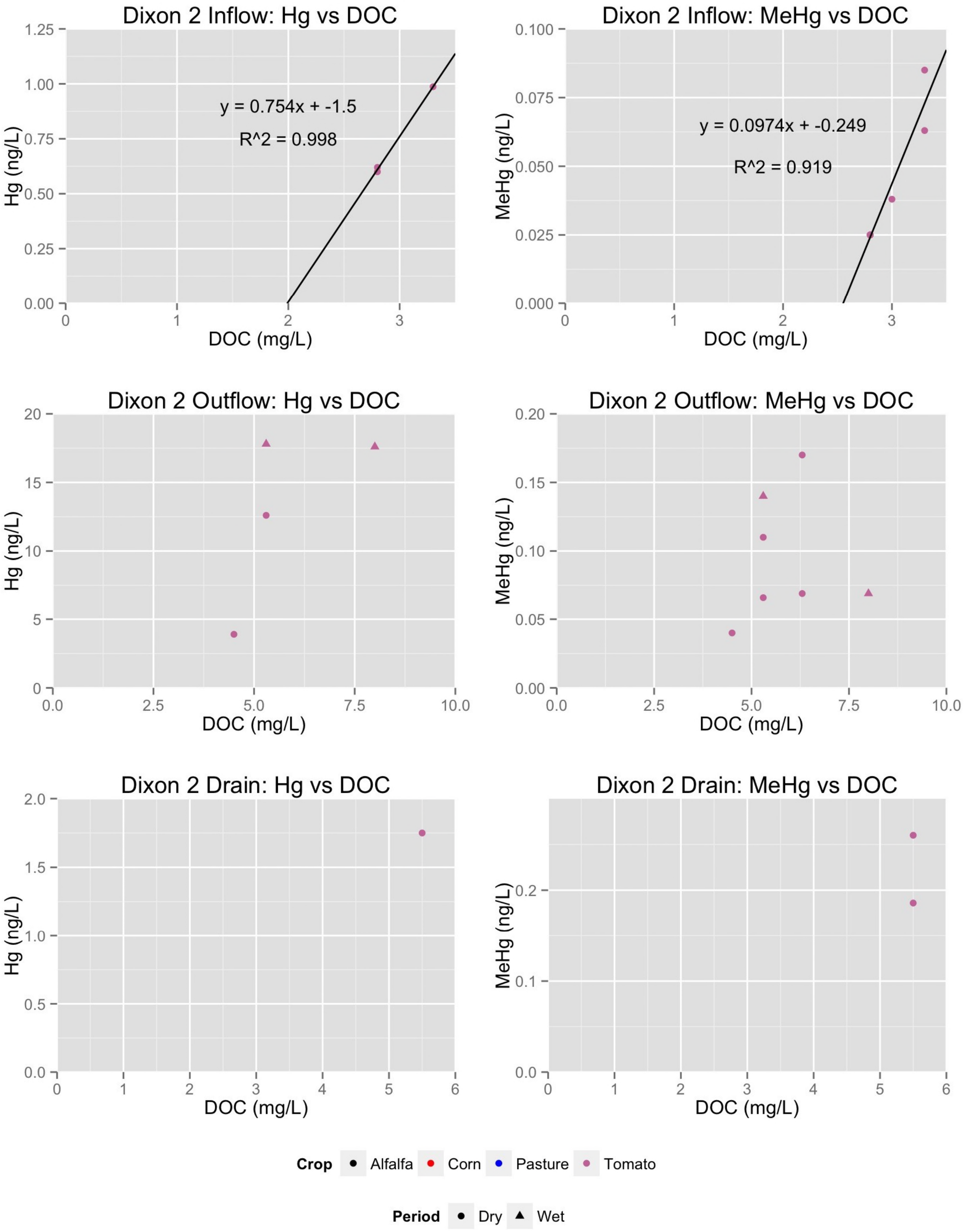


Figure B-4 Dixon 2 DOC relationships (tomato)

Inflow Hg and MeHg concentrations are seen to be elevated for larger inflow DOC concentrations.

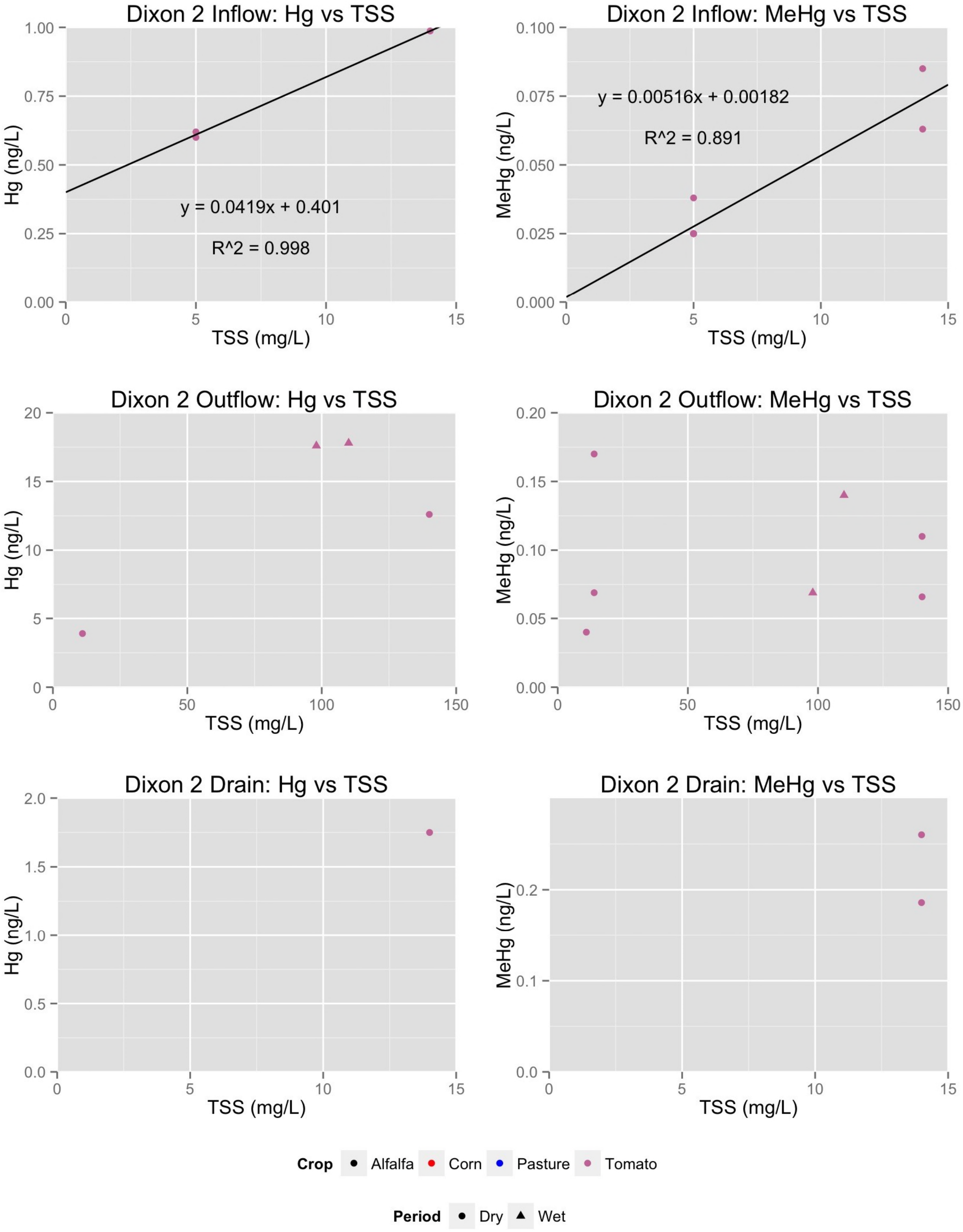


Figure B-5 Dixon 2 TSS relationships (tomato)

Inflow Hg and MeHg concentrations are seen to be elevated for larger inflow TSS concentrations.

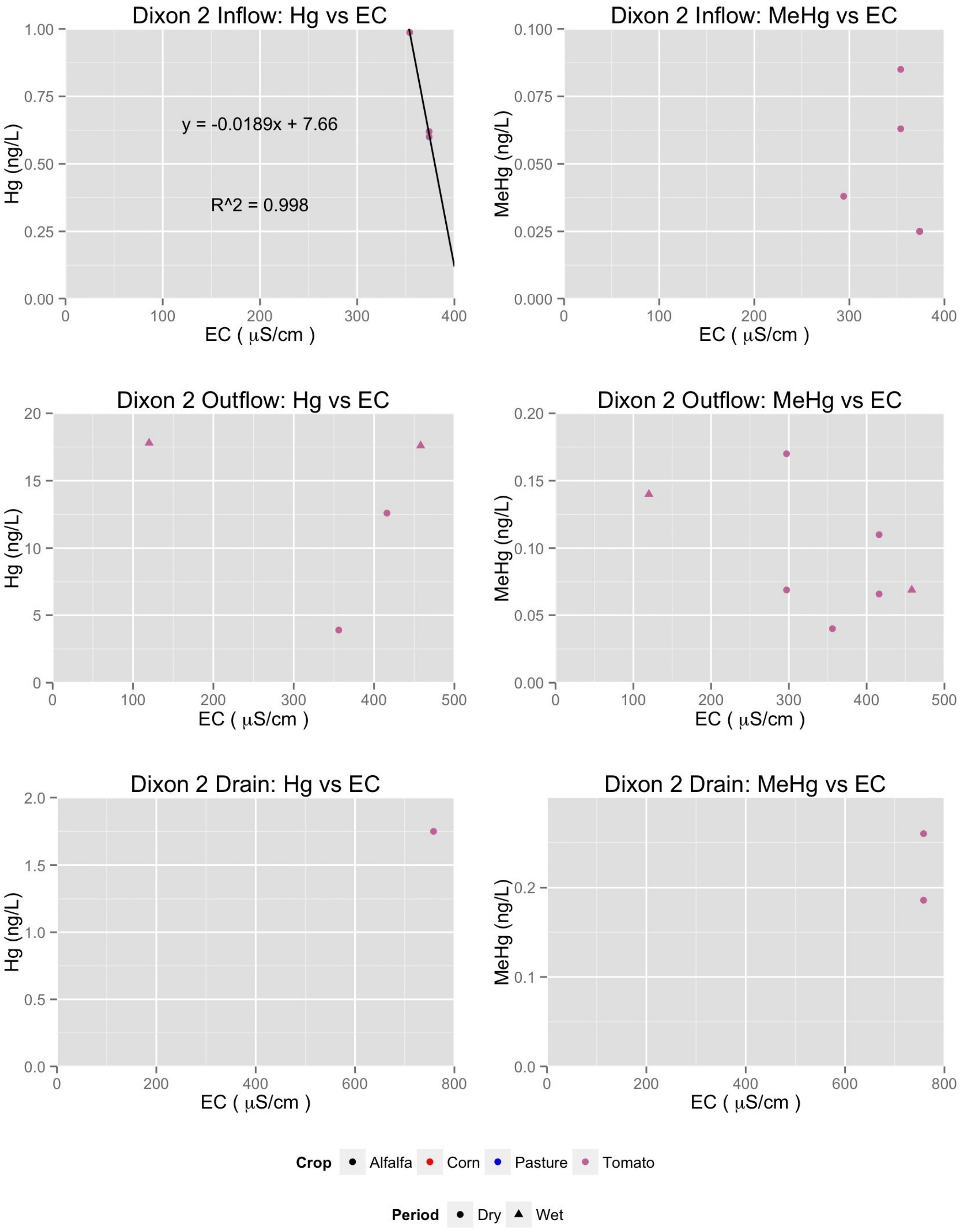


Figure B-6 Dixon 2 EC relationships (tomato)

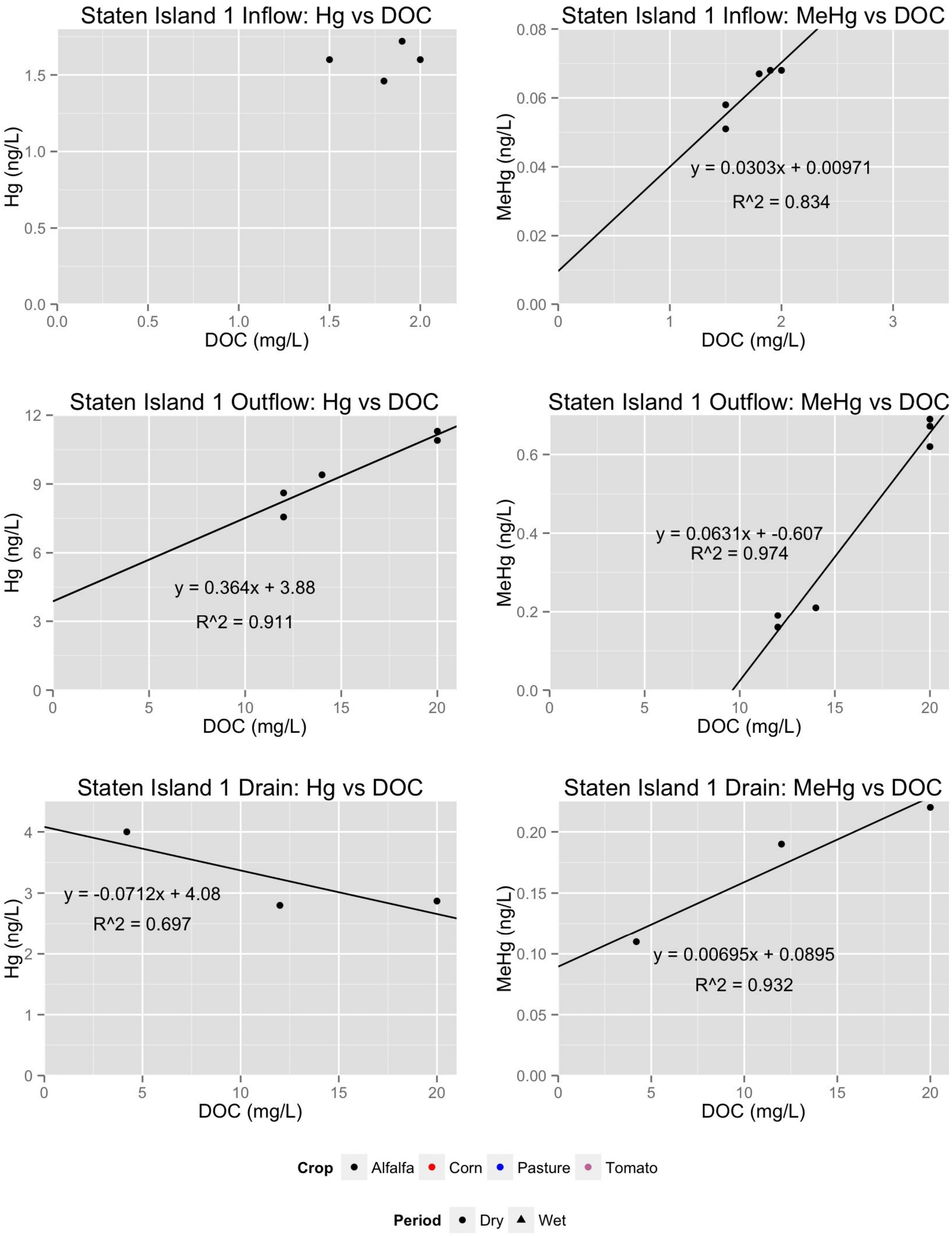


Figure B-7 Staten Island 1 DOC relationships (alfalfa)

MeHg concentrations are seen to increase with increasing DOC concentrations.

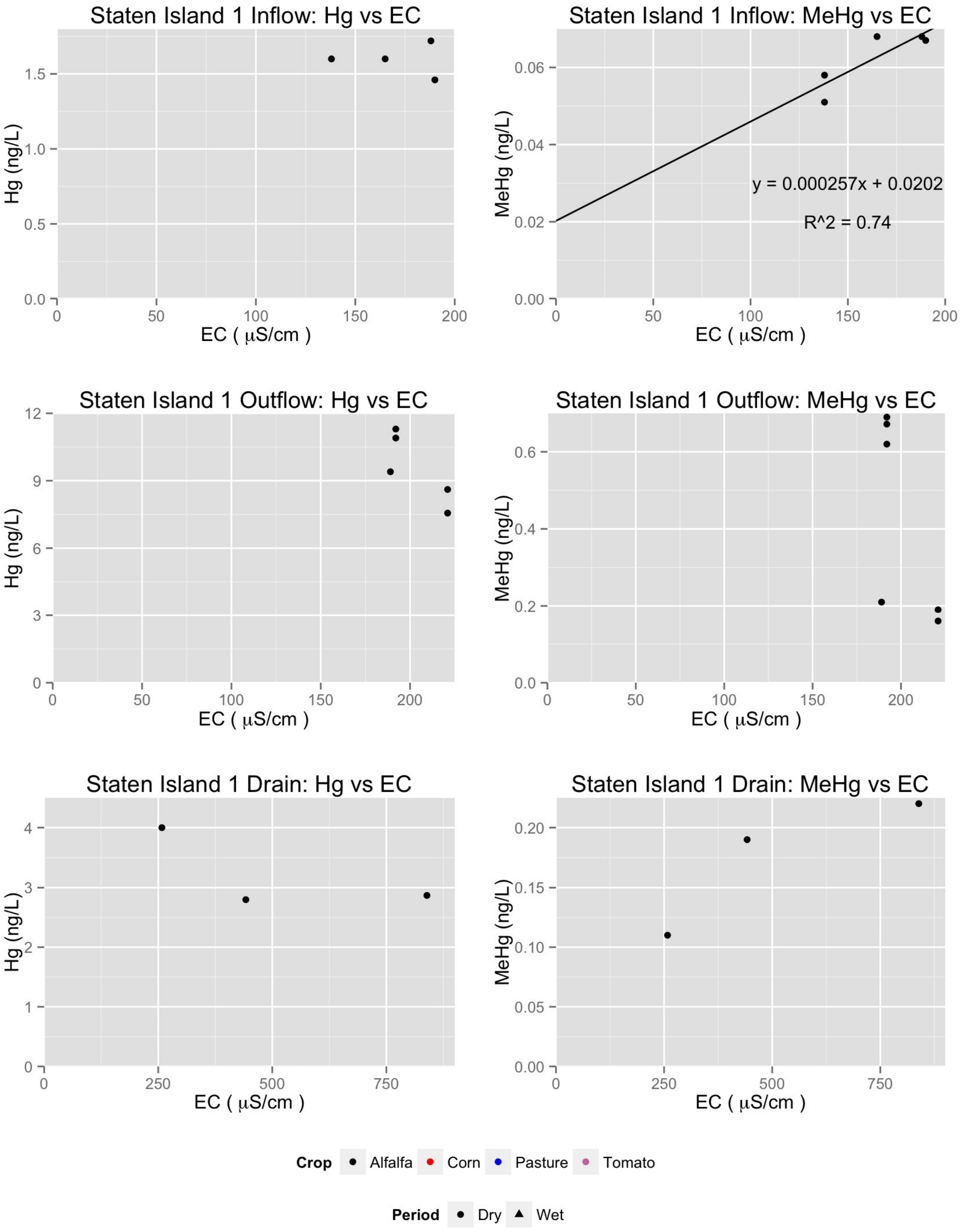


Figure B-8 Staten Island 1 EC relationships (alfalfa)

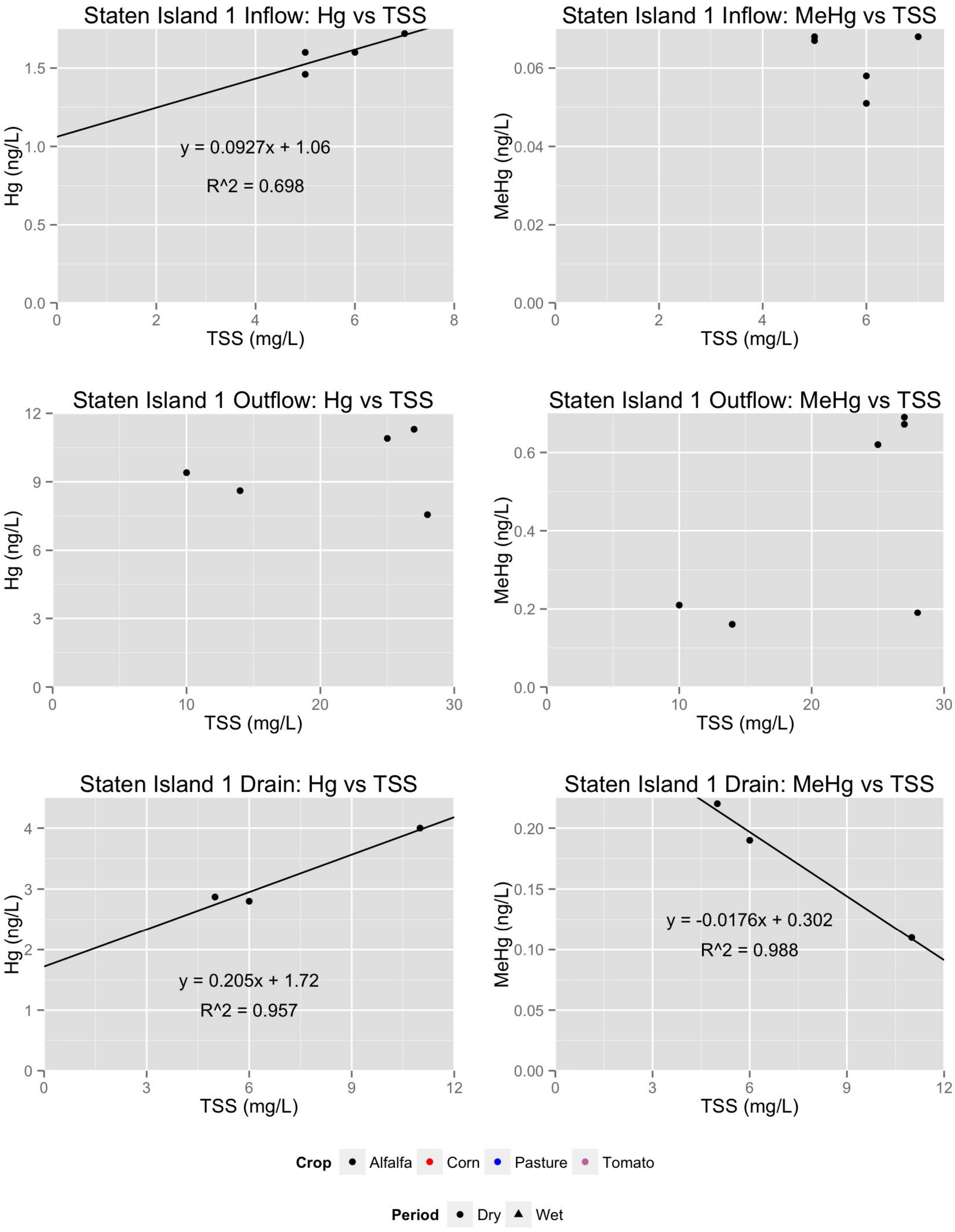
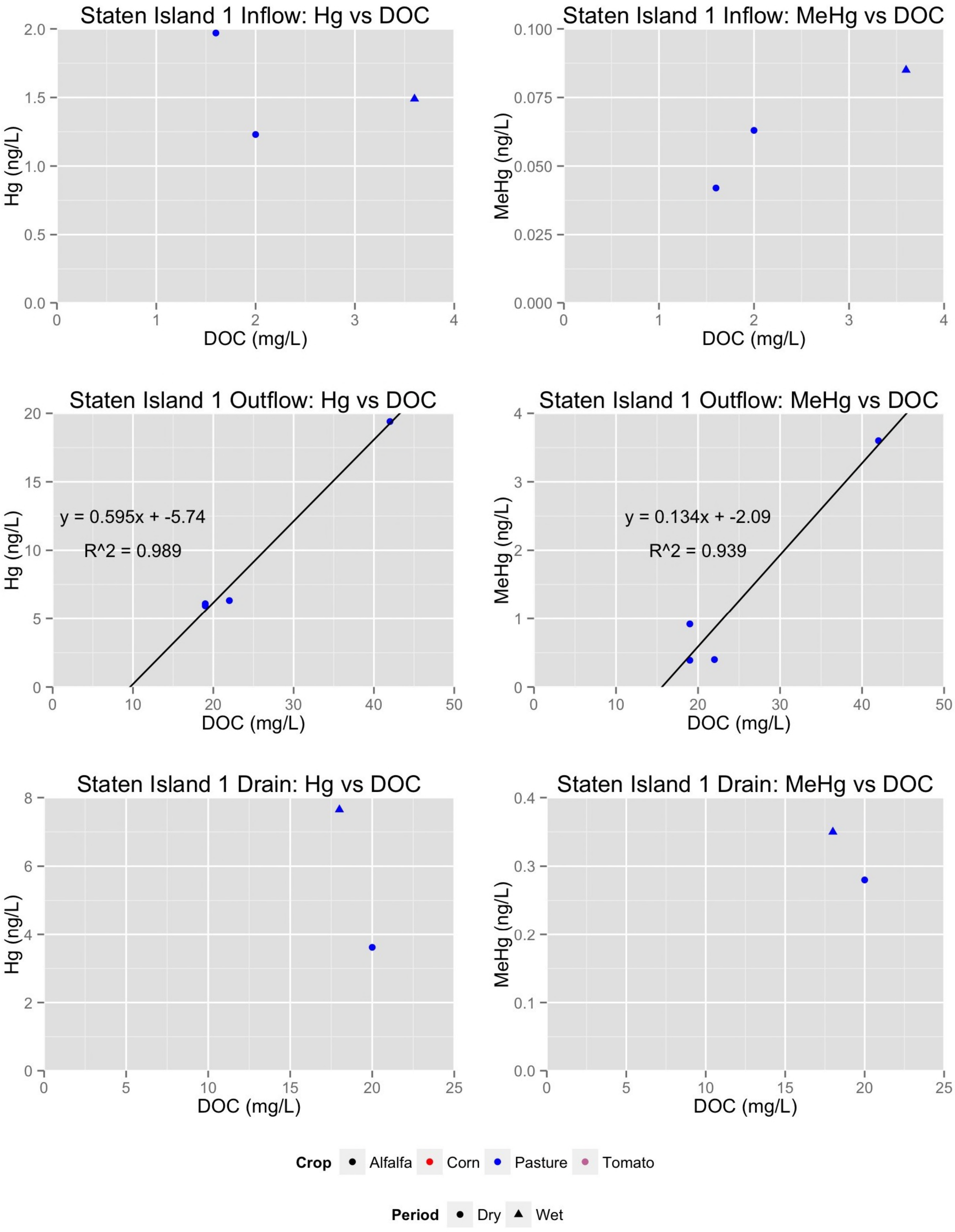


Figure B-9 Staten Island 1 TSS relationships (alfalfa)

Drain Hg concentrations are seen to increase with increasing drain TSS con- centration while drain MeHg concentrations are seen to decrease.


Staten Island 1 Inflow: Hg vs DOC

Staten Island 1 Inflow: MeHg vs DOC

Staten Island 1 Outflow: Hg vs DOC

Staten Island 1 Outflow: MeHg vs DOC

Staten Island 1 Drain: Hg vs DOC

Staten Island 1 Drain: MeHg vs DOC

Figure B-10 Staten Island 1 DOC relationships (pasture)

Outflow Hg and MeHg are seen to increase for increasing outflow DOC concentration.

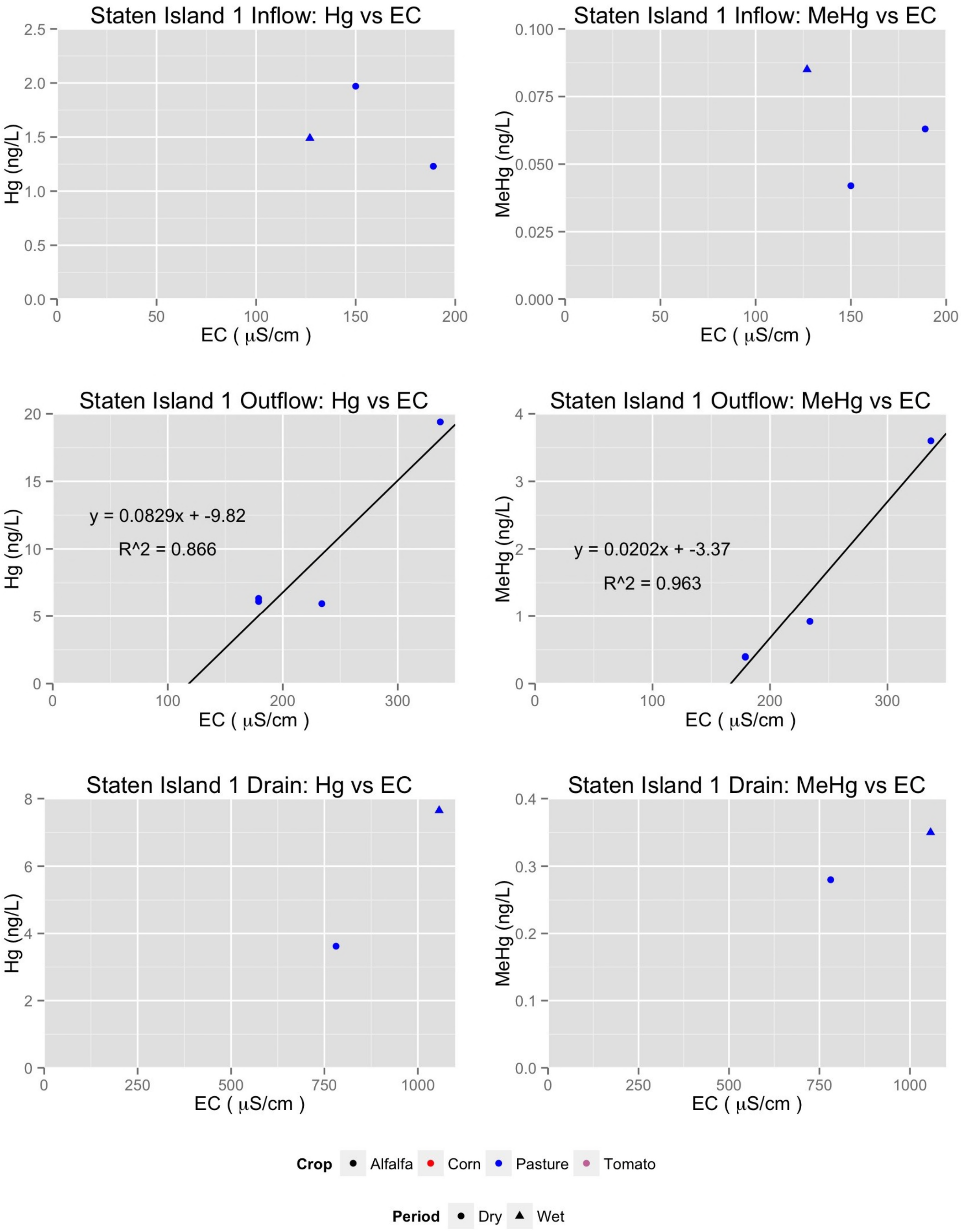


Figure B-11 Staten Island 1 EC relationships (pasture)

Outflow Hg and MeHg concentrations are seen to be larger for larger outflow EC.

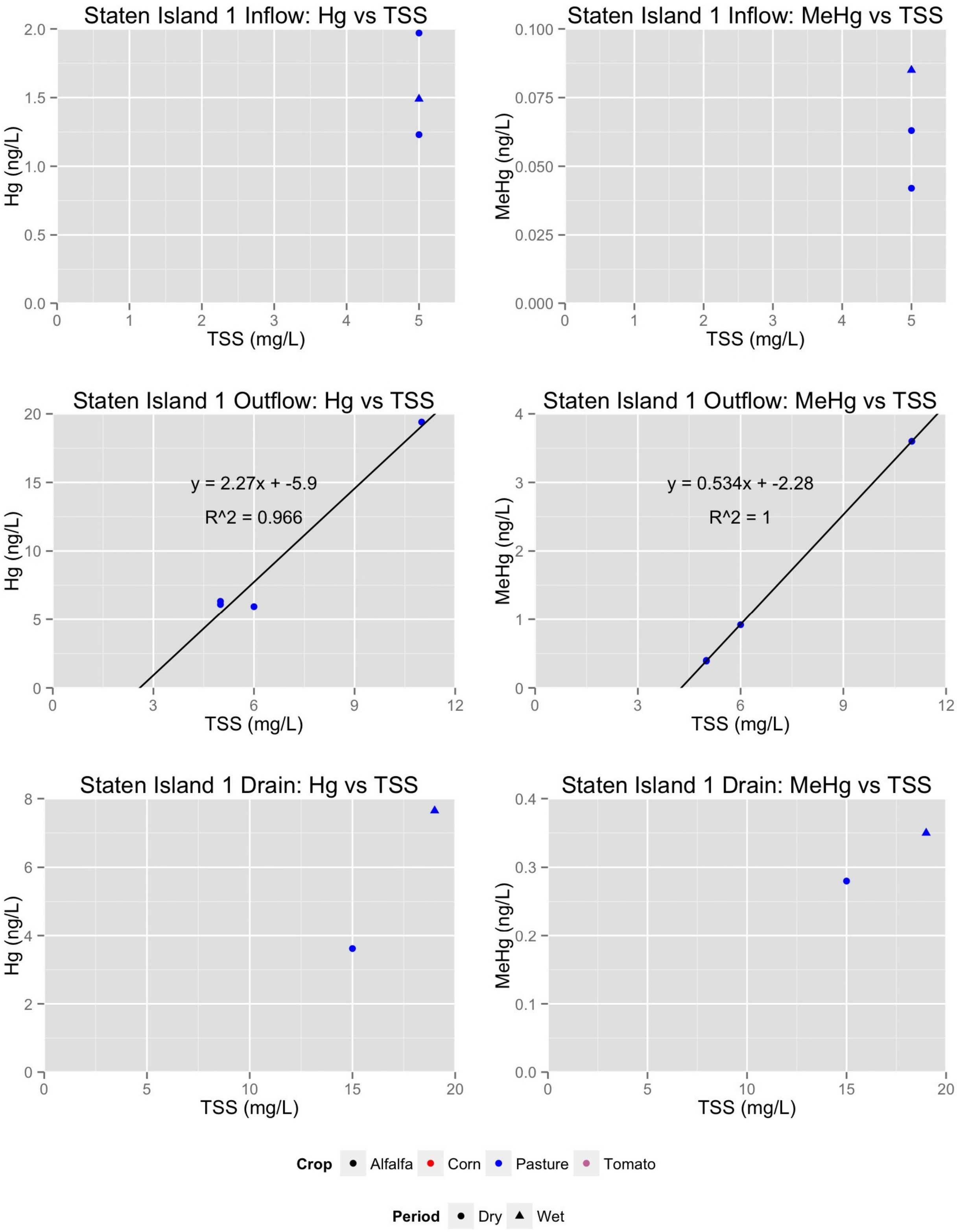


Figure B-12 Staten Island 1 TSS relationships (pasture)

B-18 Outflow Hg and MeHg concentrations are seen to increase with increasing outflow TSS concentration.

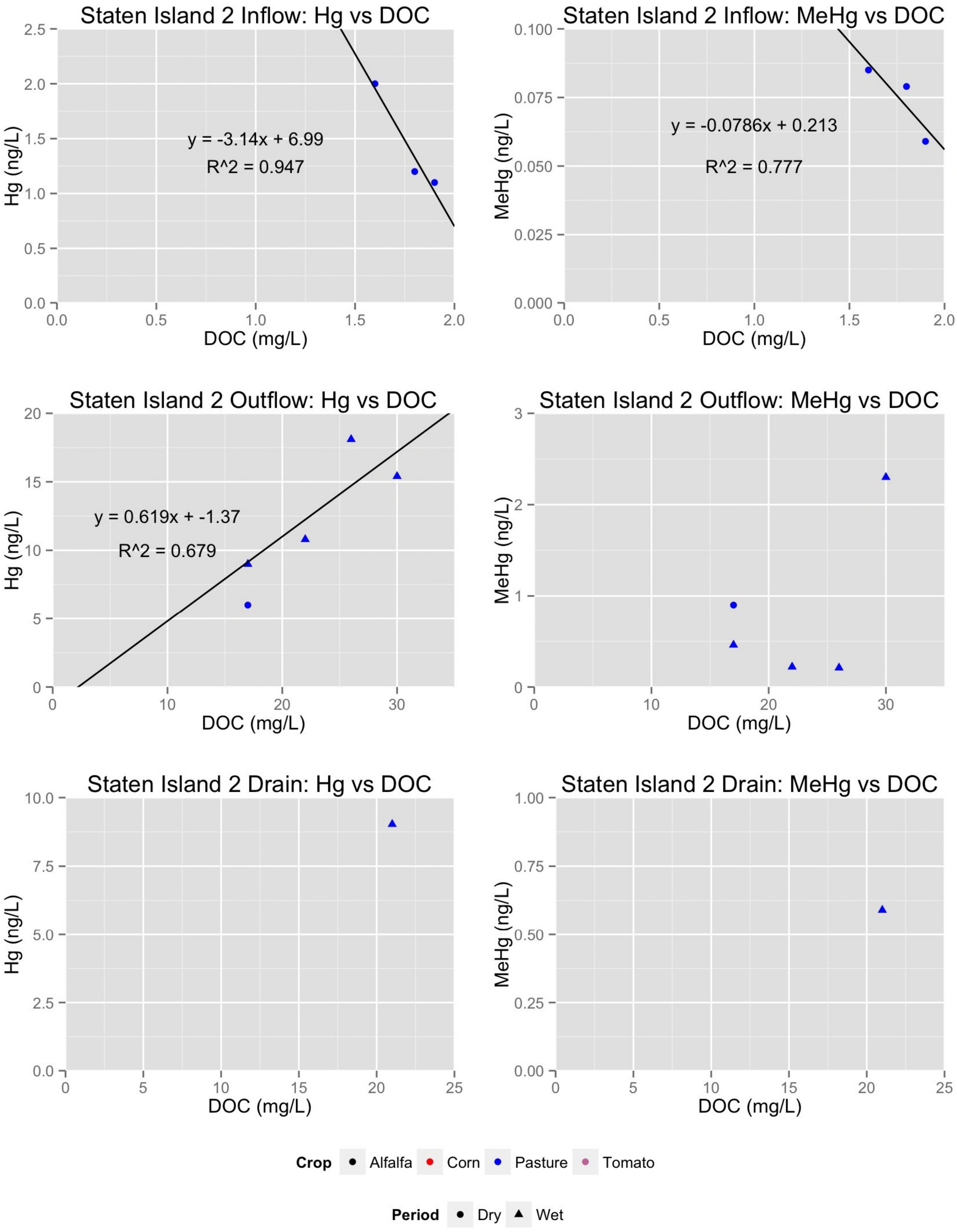


Figure B-13 Staten Island 2 DOC relationships (pasture)

Inflow Hg and MeHg concentrations are seen to decrease with increasing outflow DOC concentrations.

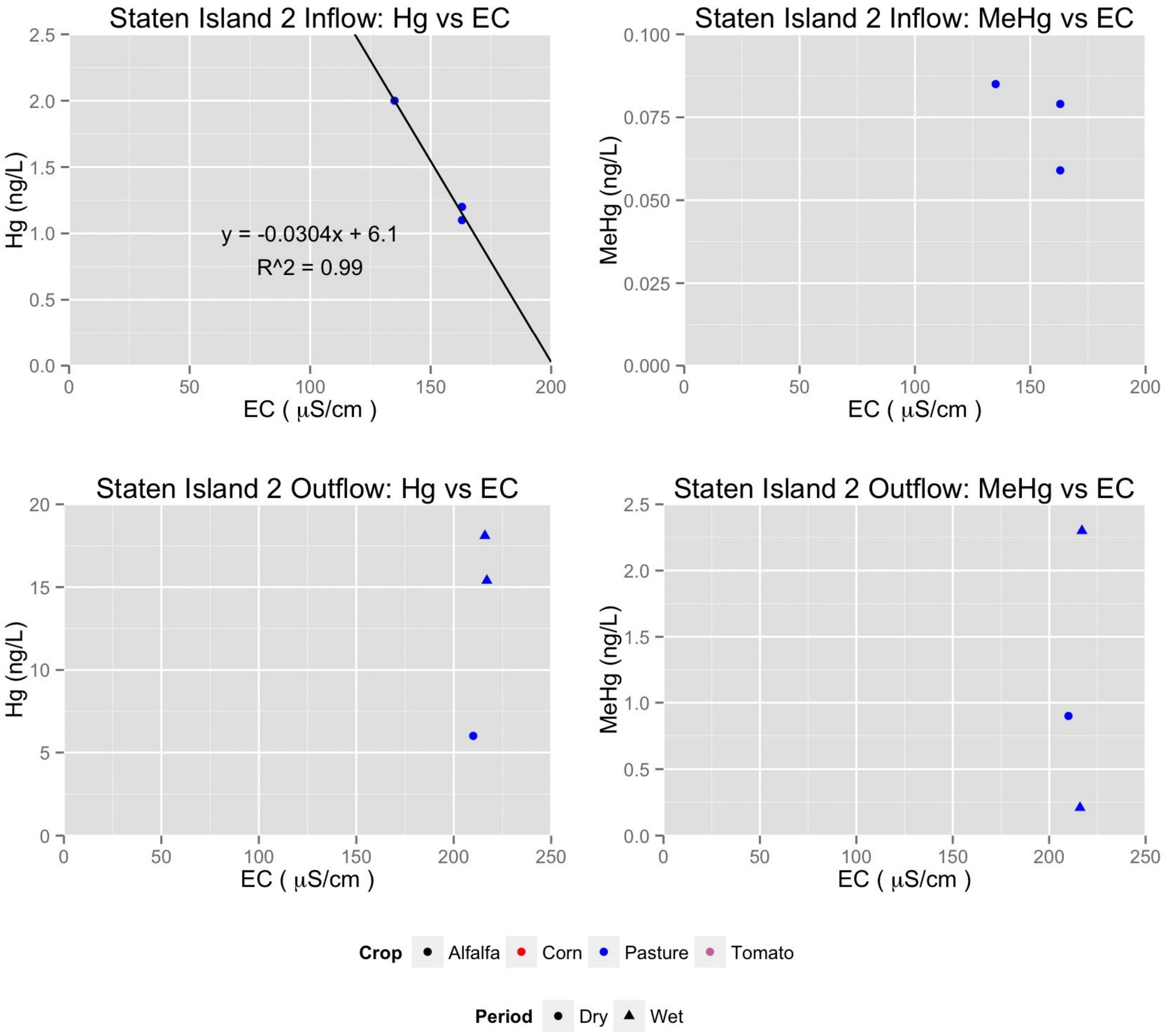
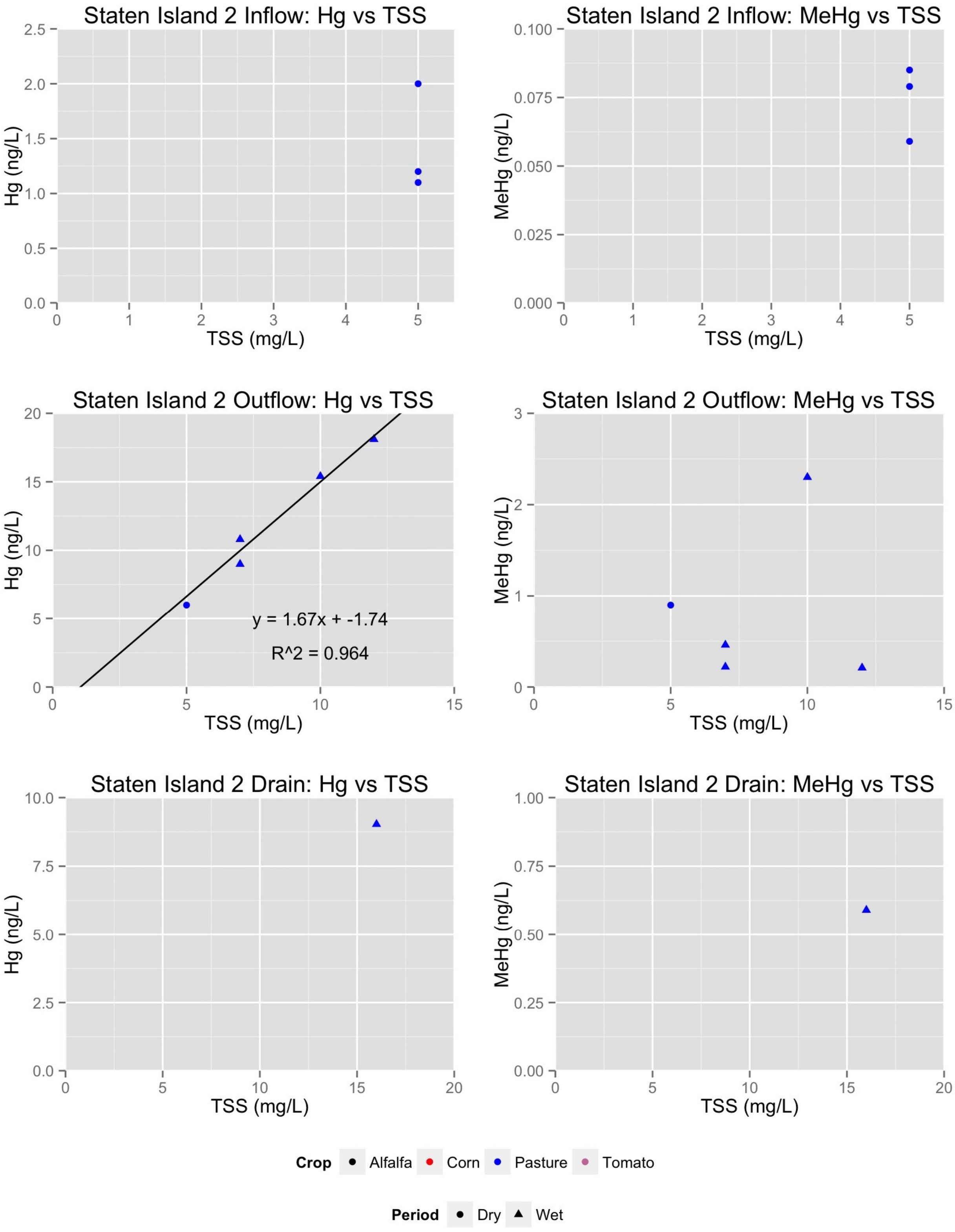


Figure B-14 Staten Island 2 EC relationships (pasture)



Staten Island 2 Inflow: Hg vs TSS

Staten Island 2 Inflow: MeHg vs TSS

Staten Island 2 Outflow: Hg vs TSS

Staten Island 2 Outflow: MeHg vs TSS

Staten Island 2 Drain: Hg vs TSS

Staten Island 2 Drain: MeHg vs TSS

Figure B-15 Staten Island 1 TSS relationships (pasture)