Appendix J: An Overview of Leakage Risk and Mitigation Approaches for Land Management Activities in Merced County, California

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This analysis provides an analysis of leakage risk for a variety of greenhouse gas (GHG) mitigation activities to be implemented by or in cooperation with Merced County, California. First provided is a literature review on the concept of leakage to ground the analysis that follows. From this, a simplified heuristic is developed to assess leakage risk from project activities envisioned for Merced County. The analysis concludes with a short review of potential mechanisms to account for, minimize, and/or otherwise address leakage.

An Overview of Theory and Empirical Evidence

In an overview of land-based carbon sinks, management, and accounting, IPCC (2000) defines leakage as “changes in emissions and removals of greenhouse gases outside the accounting system that result from activities that cause changes within the boundary of the accounting system” (p11). A similar but more detailed definition is put forth by Henders and Ostwald (2012) in their review of leakage accounting mechanisms from both the published literature and existing project accounting standards: “Carbon leakage refers to the displacement of greenhouse gas (GHG) emissions from one place to another due to emission reduction activities. It is caused by a direct or indirect shift of activities that create those emissions from within an emissions accounting system to out of that system” (p34). Though the two definitions are very similar, the latter definition is adopted in this analysis owing to its explicit consideration of direct and indirect effects.\(^1\)

Several authors have endeavored to further differentiate types of leakage within the broader category. For example, IPCC (2000) references four specific types of leakage: activity displacement, demand displacement, supply displacement, and investment crowding. Murray (2004) breaks leakage down into two separate phenomena: “Investment crowding” (uptake of activity in one area displaces what would have otherwise happened elsewhere [e.g., tree planting]) and “slippage” (reduction in production in one area inducing increased production elsewhere). In their exploration of conceptual frameworks for the analysis of leakage in project-based activities, Aukland et al. (2003) discuss leakage as either primary and secondary, or direct actor-induced, activity shifting drivers versus indirect, market-induced drivers. A similar distinction is adopted by Vöhringer et al. (2004), though they lump both into the singular category of “economic leakage”, with primary (including activity shifting) being attributable to a change in production factors (i.e., displaced individuals) and the second (including market-induced) being attributable to changes in commodity prices associated with project activity.

\(^1\) Note that this definition does not include changes in upstream or process emissions that arise as part of the activity itself (i.e., a reduction in fertilizer manufacturing emissions associated with a reduction of fertilizer use). This is not considered leakage, \textit{per se}, as it can reasonably be assumed to fall within the accounting system for that particular activity.
Schwarze et al. (2002) and Jonsson et al. (2012) similarly adopt a primary-secondary differentiation, a distinction further used herein.²

The Factors Affecting Leakage Risk and Magnitude

As a general rule, there is a risk of leakage when an activity reduces access to a particular resource without providing access to alternatives (IPCC, 2000). As Chomitz (2002) notes, “most projects have to be considered as part of integrated systems” (p38). The reduction of a particular resource, product, or commodity in one place can thus be expected to lead to an increased production of the same or substitutable resource, product, or commodity elsewhere (e.g., Wear and Murray, 2004).

Multiple authors have reviewed the factors associated with leakage risk and magnitude. Assuming that a given activity reduces the supply or a particular resource, product, or commodity, leakage will be highest when there is a relatively fixed need for that resource, product, or commodity and a relatively large area over which it could be supplied (Chomitz, 2002). Alternatively, leakage will tend to be lower when substitutes are hard to come by or users are highly sensitive to price (Chomitz, 2002; Gan and McCarl, 2007; Murray et al., 2004). Also relevant is the carbon density of targeted and non-targeted areas and the size of the market affected relative to the total (Murray, 2008).

These factors can be distilled into a more formal representation of leakage risk. In their analysis of leakage associated with U.S. forest set-asides, for example, Murray et al. (2004) develop a functional form yielding the following insights (p114):

- Leakage is enhanced the more responsive suppliers are to price;
- Leakage is enhanced the less responsive demanders are to price;
- Leakage is enhanced the higher the ratio between carbon density on non-targeted areas relative to targeted areas;
- Leakage is enhanced as the size of the restriction falls relative to the total market.

The first three points are well-represented elsewhere in the literature, but the final point is perhaps less intuitive and more contentious. As a market-driven phenomenon, leakage is moderated by changes in supply and price of given resource, product, or commodity. All else equal, affecting a small share of a particular resource relative to the total is likely to have little effect on supply (and thus price), so total quantity demanded should be similar, leading to increased production elsewhere. Thus it cannot be assumed that activities affecting a small area are without leakage risk; the opposite is in fact the case.

Evaluation of Leakage Associated with Land-Based GHG Activities

² This primary-secondary distinction is confused somewhat by previous work that refers to leakage itself as a secondary effect (and that project activities provide the primary, intended effect). See, e.g., Gershenson et al. (2011).
The literature contains multiple analyses of leakage from land-based GHG activity implementation using either partial equilibrium (PE) or computable general equilibrium (CGE) models. One seminal study, Murray et al. (2004), uses the Forest and Agricultural Sector Optimization Model (FASOM) to estimate leakage rates of forest set-aside, avoided agricultural conversion, afforestation, and joint afforestation-avoided conversion programs in the U.S. They find that leakage magnitude differs both by activity and across regions. For instance, forest set-aside programs in the Pacific Northwest were associated with less leakage (16.2%) than programs in the South Central region (68.3%) owing to the higher carbon density in the former. Allowing harvest from acres enrolled in avoided conversion programs reduced leakage but also necessarily reduced carbon storage on harvested areas.

Alig et al. (1997) also use FASOM to assess the implications of “forced” afforestation of U.S. pastureland. Similar to Murray et al. (2004), Alig et al. provides general confirmation of leakage in land-based activity implementation, showing substantial increased conversion in other land use types relative to base case, particularly in the south where the afforestation program was implemented. Elsewhere, Sohngen and Brown (2004) develop a country-specific model to assess leakage associated with secondary or market-induced leakage from retired timber concessions in Bolivia. They estimate leakage rates of 5-42% depending on different assumptions of biomass decomposition rates, capital constraints, demand elasticity, and magnitude of global sequestration efforts. Leakage is also higher in longer projects and when there is greater local reliance on products that would have otherwise been produced on retired lands.

Nepal et al. (2013a) meanwhile use the U.S. Forest Products Module and Global Forest Products Model to evaluate the potential implications of a forest carbon reserve program at different carbon prices. They find substantial leakage (71-88%) across scenarios, with rates increasing with as carbon prices increase and, due to budget-constrained nature of their hypothetical program, as enrolled acres fall. Total observed leakage rates, along with trend of higher rates of leakage associated with smaller affected market share, is consistent with Murray et al. (2004). A similar analysis is presented in Nepal et al. (2013b), though features only the two higher carbon price scenarios and places a greater emphasis on timber market impacts of the forest carbon reserves.

At the international level, Gan and McCarl (2007) assess the transnational leakage associated with national forest conservation initiatives. Using the Global Trade Analysis Project (GTAP) model, they estimate that over three-quarters of reduced forestry production in the U.S. would be shifted to other countries in the absence of global implementation of the program. Coordination between a few select countries leads to only minimal reductions in the proportion of displaced production. Lee et al. (2004) use the U.S. Agricultural Sector Model (ASMGHG) to conduct a high-level analysis of agricultural emissions under different international climate change regimes, ranging from U.S. unilateral action to global participation, finding substantial leakage in the case of unilateral action. The authors demonstrate this for U.S. action, but imply

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3 Partial equilibrium models assess changes in a limited number of sectors of the economy. CGE models assess changes economy-wide.
that leakage to the U.S. could also occur should the U.S. be the lone non-participant. In the case of global participation, U.S. prices rise and net mitigation is lower as costs are internalized.

While such analyses are useful for assessing aggregate effects and general trends, other modeling approaches have generated insight into finer scale interactions between individual actors. Delacote et al. (2015), for instance, use an agent-based model to assess the leakage implications of a variety of policy mechanisms to avoid forest conversion. Their findings are suggestive of several general trends. First, the distribution and intensity of forest loss matters. Second, the distribution of actors across a landscape matters. Third, the type of policy interacts with the spatial distribution of actors to generate either higher or lower rates of leakage.

Also represented in the literature are empirical analyses of leakage resulting from GHG mitigation and related conservation activities. These studies use a variety of data and statistical techniques to assess changes associated with implementation of a particular program or project. Wear and Murray (2004) for example provide an empirical evaluation of inter-regional shifts in timber sales following restrictions on western forest harvests put in place starting in the late 1980s. They find that consumption of timber in the U.S. is relatively unchanged in spite of western timber restrictions, suggesting substitution of supply. Although their analysis was not specifically designed to simulate the effects of carbon policy, estimated leakage rates ranged from 43% when assessing changes at the regional level, 58% when considering national changes in supply, and 84% when considering supply response at the international level.

Leakage from the Conservation Reserve Program (CRP) has likewise been debated in the literature. Over the course of several articles in the early 2000s, two author teams debated the empirical evidence for leakage in the CRP (termed “slippage” in the analyses themselves). Wu (2000) used National Resources Inventory (NRI) data to assess so-called slippage associated with CRP, finding that the program potentially contributed to increases in non-cropland conversion on the order of 30% in the Corn Belt region, 16% in Lake States, and 15% in the northern plains. Importantly, Wu also estimated net resource changes to be smaller than acreage changes, as gains in erosion benefits from set-aside areas were generally larger than losses on converted lands.

In challenging the calculated leakage rates estimated by Wu (2000), Roberts and Bucholtz (2005) cite the fact that areas that are likely to have more acres enter the CRP are also likely to have more marginal acres be removed from production for some other reason. They find no consistent evidence for leakage in the CRP, noting that the data used cannot be used to estimate secondary (“price feedback effect”) leakage and that primary (“substitution effect”) leakage is difficult to estimate given the array of factors that influence individual farmer decision-making. In a response, Wu (2005) refutes many of the claims offered by Roberts and Bucholtz (2005), restating that both the original (Wu, 2000) and commenting piece (Roberts and Bucholtz, 2005) show evidence of significant slippage under the CRP. A subsequent and final rejoinder (Roberts and Bucholtz, 2006) refers to the potential for substitution effects as “partially valid” (p513) but suggests that they are likely to be small given high turnover observed in agricultural land markets.
Boer et al. (2007) use a logit model to assess likelihood of land use conversion and potential leakage associated with forest restoration projects in Indonesia. In their analysis, the authors used satellite imagery and other available data to generate estimates of land use change associated with individual project activities. Though useful and informative, the authors also reflect on the data-intensive and time-constrained nature of their approach. They specifically caution that approaches such as theirs should not be used to estimate trends far into the future, as it is necessary to make assumptions on what is driving observed changes.

Finally, Alix-Garcia et al. (2012) use matched plots to assess the effectiveness of a forest conservation payment program in Mexico, finding evidence of both substitution or activity-shifting (primary) and price-induced (secondary) leakage, or “slippage” as they term it. They find evidence of activity-shifting leakage at both very low and very high poverty rates, but observe that the direction of effect varies, with negative leakage occurring in areas of high poverty and positive, spillover-type effects occurring in low poverty areas. They likewise discuss the seriousness of the leakage threat, but also the difficulty in actually observing it unless markets are small and price changes are localized.

**Risk and Accounting Mechanisms for Activities in Merced County, California**

The literature has demonstrated the theoretical basis and empirical evidence for leakage in forest and agricultural GHG mitigation activities. The next step in this analysis is to further consider the specific leakage risks posed by activities considered for implementation in Merced County and the best mechanisms for accounting for that risk. A subsequent section will then review the potential approaches for mitigating leakage risk to the maximum extent possible.

As reviewed above, leakage is a potential problem when a given activity reduces the supply of a particular resource, product, or commodity. This general phenomenon can be viewed through the lens of activities under consideration in Merced County. Activities that affect agricultural yields, for example, can be expected to generate some degree of leakage (Müller-Lindenlauf, 2009). Conservation activities, including avoided deforestation, are likewise subject to both activity-shifting (primary) and market-induced (secondary) leakage (Aukland et al., 2003). Alternatively, improved practice projects, such as agricultural intensification or reduced impact logging, can potentially avoid both types of leakage so long as existing land uses are not affected and a constant supply of outputs is maintained (Aukland et al., 2003; Müller-Lindenlauf, 2009). Assumptions of minimal leakage also apply to situations where there is not a current market for a given output, such as in the case of urban forestry activities (Poudyal et al., 2011).

There are on the order of ten separate activities and ten separate land uses considered by TNC and the County; even if not all activities are relevant to every land use, the number of possible permutations is quite large. To create a tractable approach for evaluating leakage across these multiple and varied combinations, this analysis begins with a screening exercise based on the degree to which an activity affects the supply of a particular resource, product, or commodity. A
rough simplification of possible start (baseline) and end (project activity) conditions for activities considered in this project yields six separate configurations:

1. **Baseline:** Land is managed for some commercial amenity, output, or commodity; **Project Activity:** Land will no longer be managed for or displaces some marketable commercial amenity, output, or commodity.
2. **Baseline:** Land is managed for some commercial amenity, output, or commodity; **Project Activity:** Land will be managed for or displaces some other marketable commercial amenity, output, or commodity.
3. **Baseline:** Land is not managed for some commercial amenity, output, or commodity; **Project Activity:** Land use changes, but is still not managed for or displaces a marketable commercial amenity, output, or commodity.
4. **Baseline:** Land is not managed for some commercial amenity, output, or commodity; **Project Activity:** Land use changes, and will now be managed for or displaces some other marketable commercial amenity, output, or commodity.
5. **Baseline:** Land is not managed for some commercial amenity, output, or commodity; **Project Activity:** Change in management strategy only, with no change in land use or output.
6. **Baseline:** Land is managed for some commercial amenity, output, or commodity; **Project Activity:** Change in management strategy only, with no change in land use or output.

The general activities under consideration for Merced County can then be arrayed across these conditions (Table 1). Generally speaking, activities falling into the first and second categories face the greatest potential for leakage. The extent to which the risk of leakage rises above some minimal or de minimis level is dependent upon the particulars of the activity, such as the land use currently in place, the new land use, the carbon content of both uses, and affected markets. The balance of the analysis will then focus on how to assess the effect of these particulars on activity leakage risk.

From Table 1, a subset of activities can be excluded from further analysis owing to their minimal leakage risks. Improved Nitrogen Fertilizer Management and Replacing Synthetic Nitrogen Fertilizer with Soil Amendments activities, for example, are unlikely to generate significant leakage so long as yields are maintained. There is the theoretical potential for some expansion of synthetic fertilizer use to occur if reduction of use in Merced County led to a decline in price of the product, but that risk is assumed to be very small. The leakage risk associated with Mulching is also assumed to be very small, again so long as yields are maintained. Finally, Urban Forestry can be assumed to generate little or no leakage due to the general absence of a market for associated products. For the balance of activities included in Table 1, some manner of leakage accounting is prudent, even if only to show that a particular activity in a particular instance poses little risk. To do so first requires a review of the unique circumstances surrounding each activity.4

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4 Note that definitions for each activity are derived from information listed in the document “Activity Definitions_171222.pdf” (J. Remucal, Pers. Comm., 22 December 2017).
### Table J.1. Start and end conditions for activities considered for implementation in Merced County.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Currently in marketable use, displaces/shifts away from marketable use</th>
<th>Currently in marketable use, displaces/shifts to some other marketable use</th>
<th>Currently not in marketable use, displaces/shifts to some other non-marketable use</th>
<th>Currently not in marketable use, no change in output</th>
<th>Currently not in marketable use, no change in output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avoided Conversion</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Improved Nitrogen Fertilizer Management</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Replacing synthetic fertilizer with soil amendments</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Restoration of Oak Woodlands</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Cover Crops</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mulching</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Riparian Restoration</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Urban Forestry</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Improved Forest Management</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Fallowing</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hedgerow Planting</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

**Avoided Conversion:** The activity area is permanently protected through zoning changes (e.g., to open space) or conservation easements that dedicate the project area to a natural condition. The project area may be used for a variety of purposes that maintain the natural land cover.

- **Primary:** some degree of conversion could still occur, just elsewhere in the immediate vicinity.
- **Secondary:** some degree of new conversion occurs elsewhere in response to decrease in supply of given commodity. The magnitude of risk will depend on the specialization and localization of market affected, with highly localized or specialized markets tending to have smaller risks of secondary leakage.

**Cover Crops:** Activity reductions are based on adding either seasonal leguminous or non-leguminous cover crops that supply partial fertilizer demand to irrigated commodity crops, thus reducing fertilizer application. Other cropland management practices remain the same with adoption of the conservation practice.

- **Primary:** it is possible that an individual actor may wish to change cropping practices to make up for foregone supply associated with cover cropping.
- **Secondary:** some degree of new conversion could occur elsewhere in response to a decrease in supply of given commodity. To the extent that cover crops are themselves introducing a new commodity, there may be positive leakage effects that may counter any displaced production from primary crop.
Hedgerow Planting: Reductions result from replacing conventionally managed and fertilized annual cropland with one row of unfertilized, woody plants.

- Primary: it is possible that an individual actor may wish to change cropping practices to make up for foregone supply associated with land set aside for conversion to hedgerow.
- Secondary: some degree of new conversion could occur elsewhere in response to decrease in supply of given commodity.

Oak Woodland Restoration: Reductions are the results of the restoration of grasslands to native oak woodland cover in ecologically appropriate areas.

- Primary: it is possible that an individual actor may wish to change management practices to make up for foregone services associated with area restored.
- Secondary: some degree of new conversion could occur elsewhere in response to decrease in supply of given commodity.

Riparian Restoration: Reductions are the result of woody plantings on degraded streambanks, which are characterized by lack of vegetation, allowing the movement of heavy runoff through the riparian zone directly into stream channels.

- Primary: it is possible that an individual actor may wish to change cropping practices to make up for foregone supply associated with cover cropping.
- Secondary: some degree of new conversion could occur elsewhere in response to decrease in supply of given commodity.

Improved Forest Management: Reductions are the result of increased productivity of managed forest systems. This can be yielded through either extended rotations for even-aged systems so as to sequester more carbon on the stump or in eventual wood products, and/or through increased productivity of the stand as a whole through appropriate silvicultural practices.

- Primary: it is possible that an individual actor may shift harvest activity to other holdings if activities (e.g., rotation extension) result in a decline in forest product yield.
- Secondary: additional harvests could occur if the activity results in a reduction in the supply or a change in the type of forest products either over the short or long term.

Having documented the factors influencing leakage in each activity type, the next step is to account for the magnitude of leakage risk associated with each activity type. Primary leakage occurs either in the immediate vicinity of the displaced activity or on lands held or managed by affected actors. As such, it is perhaps better addressed through pre-activity planning and post-activity monitoring. Secondary leakage is more difficult to observe, though as described above, the literature suggests that the magnitude of leakage is associated with the price responsiveness of both suppliers and demanders, the ratio of carbon density between target and non-targeted affected areas, and the size of activity relative to the full market for that activity (e.g., Murray et al., 2004).

The literature also details multiple approaches by which leakage risk can be estimated for a variety of projects, programs, and activities. Henders and Ostwald (2012), for example, review leakage accounting approaches for multiple types of land-based GHG mitigation activities,
including the use of generic discount factors to account for secondary leakage, many of which adjust the magnitude by site conditions (carbon content, carbon intensity of activities, etc.). They also review the use of qualitative assessments such as interviews or surveys to gauge the extent to which individuals engage in practices generating or leading to leakage.

Elsewhere in the literature, the leakage associated with particular activities or programs are estimated through the use of economic models or empirical data specific to the activity in question (see “Evaluation of Leakage Associated with Land-Based GHG Activities,” above). In the absence of economic models to estimate leakage, rough approximations can also be generated using estimates of supply and demand function response (Murray, 2008). VCS (2017), for example, recommends basing secondary leakage on estimates of supply/demand elasticities and peer-reviewed approach for estimating leakage rates.

Henders and Ostwald (2012) suggest using historical averages to establish baseline of logging activity, then monitoring of activity under project to see whether volume changes with deductions made to reported carbon benefits if necessary (see also Schwarze et al., 2002). Wu (2000) argues that price-induced slippage (similar in concept to secondary leakage) stemming from conservation program implementation requires time-series data on prices, program enrollment trends, and land use change to estimate net effect. Vöhringer et al. (2004) meanwhile suggest first specifying the drivers of leakage by identifying market leakage effects (i.e., causes). From there, leakage factors should be established using applied economic models, with the option for individual project proponents to petition to use some other (presumably reduced) emission factor.

At a programmatic level, however, Identification of the factors influencing leakage magnitude and the most appropriate process for estimating risk is perhaps a task easier said than done. Schwarze et al. (2002) note that leakage from forest conservation projects (i.e., avoided deforestation and improved management) and afforestation projects will depend on both the particulars of the project and specific site and market conditions. Atmadja and Verchot (2012) likewise summarize leakage estimates for a variety of land use and non-land use activities using a variety of analytical approaches, finding an incredibly wide range in leakage estimates: -44% to 279% across activities, studies, and scenarios. Diaz et al. (2015) provide a comprehensive review of leakage approaches and estimates in the context of soil sequestration projects and, in doing so, report a range of 2%-89%, varying by space and over short versus long time periods.

Though it is difficult to select a single value that best reflects the leakage risk associated with the variety of activities potentially undertaken in Merced County, a decision tree-type approach provided by Air Resources Board (2015) provides a model for how one might winnow the list down to those activity configurations with the greatest risk. Key parameters of the decision tree include the previous use of the project area, the economic viability of the previous activity on the project area, and the expected magnitude of displacement of the previous activity. This process essentially follows the following logic: was something else there, was it commercially viable, and if so, how much are you encouraging to be produced off-site.
A similar conceptual map is adopted for activities here. Shown in Figure 1 is a hypothetical flow chart to guide leakage risk determination for management-based and avoided conversion activities. The first two decision points of this flow chart are predicated on the literature above, that there is a risk of secondary or market-induced leakage when an activity reduces the supply of some product, commodity, or service. The third meanwhile provides a check for the geographic reach of the affected market, using jurisdictional boundaries.

The fourth and fifth decision points attempt to reach some conclusion on the relative magnitude of leakage risk, but also reflect the practical difficulties that accompany the establishment of a standardized process for an activity-specific phenomenon. These decision points necessarily require simplification so as to make the flow chart applicable to the widest possible range of activities. An alternative would be to leave it up to the user to calculate specific leakage estimates unique to their particular situation. The flow chart reflects the former approach. The fourth decision point, for example, makes a distinction between short- and long-term impacts. Long-term shifts in production may elicit a greater market response than short term perturbations. The fifth decision point requires a balancing of opposing perspectives. Shifts in production that are small relative to the overall size of the market are likely to be associated with higher rates of leakage than those that comprise a larger share of the overall market (e.g., Murray et al., 2004). For the purposes of this analysis, one may assume that affected production represents a small share of the overall market. The implication of this assumption is that there may be little difference in leakage risk regardless of the magnitude of shift in production on lands affected by the activity. Instead, the flow chart implicitly rewards activities that minimize potential shifts in production by assuming a de minimis risk of leakage.

Alternatively, activities that may result in larger shifts in production are assigned default leakage risks from the literature. Leakage deductions for cropping systems approximated from estimates reported in Diaz et al. (2015), Wu (2000), and Roberts and Bucholtz (2005). Leakage deductions for forest systems approximated from estimates reported in Murray et al. (2004), Wear and Murray (2004). With fewer estimates located that specifically assess leakage in grazing, and vineyard and orchard systems, leakage rates are assumed to be similar to cropping systems for the first and similar to forest systems for the latter two.

It is important to again remind the reader that leakage is an intervention-specific phenomenon. There are inherent tensions between development of a simplified tool for evaluating the magnitude of leakage risk for whole classes of activities and derivation of specific estimates of leakage risk based upon the unique market and carbon parameters of the specific activity in question. For example, one reviewer of this review notes that total production of certain commodities in some California counties could represent a sizable share of the global market, complicating the assumption of small market share. But if one assumes a functional form like that derived by Murray et al. (2004) to characterize leakage risk, there is no market share threshold, per se, of when leakage becomes more of a concern, only a trend that leakage tends to increase as the share of total production affected falls. The figure below also does not capture the carbon density of affected land uses, nor does it fully consider the price elasticities of supply or demand. The value of the figure below should thus be seen in its conceptualization
of the process for considering whether leakage is of concern, and less in the particular values assigned at the end.

**Figure H.1. Flow chart to determine default leakage risk for land-based GHG management and avoided conversion activities in Merced County.**

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes</th>
<th>No - No leakage assumed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is the activity affecting the production of a particular product, commodity, or service?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is the activity resulting in a reduction of a particular product, commodity, or service?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is the displaced product, commodity, or service likely to shift outside of the controlling jurisdiction?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>How long is reduction in a particular product, commodity, or service expected to last?</td>
<td>&gt; 1 rotation or season, ≤ 1 rotation or season - Leakage assumed to be <em>de minimis</em></td>
<td></td>
</tr>
<tr>
<td>How much will production of a product, commodity, or service be reduced as a result of the activity?</td>
<td>&gt;25%</td>
<td>Leakage assumed to be <em>de minimis</em></td>
</tr>
<tr>
<td></td>
<td>≤25%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Leakage Discount...</td>
<td></td>
</tr>
<tr>
<td></td>
<td>For cropping systems: 25%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>For grazing systems: 25%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>For orchard/vineyards: 40%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>For forest systems: 40%</td>
<td></td>
</tr>
</tbody>
</table>

The above figure attempts to capture leakage risk from both management-based and avoided conversion activities. Avoided conversion requires a slightly different perspective than management-based decisions as any leakage will stem from the displacement of some new practice, meaning that leakage results from what is not done rather than what is. Consideration of such situations is further complicated when there is the potential to affect multiple product streams. For example, conversion of productive timberland to urban use involves the displacement of forest products that were produced on that site. Avoided conversion of that same timberland allows for forest production to continue, but risks displacing urban development to some other area. Strictly viewing the situation from a leakage perspective, however, it is only the latter set – displacement of the avoided use – that are considered here.
Avoided conversion is also complicated in that conversion pressures may stem from localized phenomena like urban development. In those specific cases where displaced activities are unlikely to shift outside of the jurisdiction in which the avoided conversion activity is taking place, it may be more appropriate to manage leakage risk through project design or through external programs operated by or at the county level, such as those encouraging infill development under SB375, the Sustainable Communities and Climate Protection Act of 2008.

Finally, note that the figure does not attempt to assess the carbon effects of land use or land management changes, including changes in relative carbon density on land where the activity takes place or the land to which production shifts. Rather, it attempts to focus the user on those situations where leakage may be of greatest concern and to identify a reasonable approximation of the magnitude of production shifts. As noted above, more precise estimates of leakage require activity-specific evaluation of supply and demand price elasticities, relative carbon densities of affected lands, and estimation of the relative share of the market affected (Murray et al., 2004), each of which is beyond the scope of this analysis.

The above flow chart is intended to address secondary, market-induced leakage. The literature suggests that primary, activity-shifting leakage is perhaps better handled through activity design and management at the jurisdictional (e.g., county) level. It is possible to minimize secondary leakage through activity design, as well. Approaches for both are reviewed briefly below.

**Potential Risk Mitigation Mechanisms for Activities in Merced County, California**

The literature is consistent in finding that leakage could be a serious risk to GHG project integrity, with multiple authors using strong language in their recommendations to address the phenomenon through program design or accounting (e.g., Alix-Garcia et al., 2012; Murray, 2008; Gan and McCarl, 2007; Murray et al., 2004; Schwarze et al., 2002). The literature also suggests that primary or activity-shifting leakage is a problem perhaps best addressed through project design, contracting, monitoring, and enforcement. Secondary or market leakage may be addressed somewhat by minimizing the reduction of a particular asset or commodity within the activity itself, but also requires some estimate of displaced storage or emissions that occur elsewhere. These approaches are further described below.

**Generalized Approaches for Mitigating Leakage**

Leakage is not only a function of the markets affected, but also the carbon content of the affected landscape. Owing to differences in resource attributes across the landscape, there is a need for careful consideration of where to undertake project activities so as not to enhance leakage (e.g., Renwick et al., 2015). In the present context, this implies that the opportunistic protection of a given area can yield higher degrees of leakage if the carbon content of that area is lower than landscape average.

Time is also important to consider. Aukland et al. (2003) argue that leakage should be assessed over the lifetime of the activity, as actor behavior may shift in response to changing market
conditions. Sohngen and Brown (2004) find important differences in leakage estimates for projects of different durations.

Finally, the scale of program operation and monitoring is important to acknowledge. Murray (2008) notes anecdotally that increasing scale of coverage can help to reduce (but not eliminate) leakage, i.e. a shift from project-level to national accounting. Leakage is also reduced when expanding the total number of participating jurisdictions. In the absence of universal participation, it could be helpful to add a discount such that leakage penalty is reduced as participation increases (Murray 2008).

These considerations have been combined to various degrees in practice. For instance, IPCC (2000) implicitly endorses a two-stage approach: 1. Assign small monitoring area to projects with small potential leakage. 2. For projects expected to have larger leakage, expand monitoring area to encompass expected activities and then account for observed leakage either through monitoring of key indicators for evidence of leakage or assign (and update as needed) standardized adjustment coefficients. Henders and Ostwald (2012) meanwhile relate a “minimize then discount” strategy for leakage minimization, focusing on reducing the risks of leakage through appropriate project design (or exclusion) then accounting for any remaining risk through appropriate methodologies such as discounting.

**Project Design Considerations for Addressing Leakage**

Project design plays an important role in minimizing leakage (Auckland et al., 2003). Site selection, particular selection of sites with limited or no competing uses, is one means to address leakage (Schwarze et al., 2002). The inclusion of multiple products, commodities, or services so as to avoid displacement of production is another mechanism to address leakage through project design (Schwarze et al., 2002; Chomitz 2000). For example, Chomitz (2002) offers a solution that falls partly between that suggested by IPCC (2000) and Henders and Ostwald (2012), specifically either expanding the area incorporated in the project, thus internalizing any leakage, or designing the project in such a way as to counteract any leakage from the start (e.g., linking forest protection with intensification of grazing operations).

An alternative is to use an ex post true-up for leakage as proposed by van Oosterzee et al. (2012), in which no upfront discount is required but observed leakage must be addressed via payout to buyers by the project after-the-fact. van Oosterzee et al. (2012) argue that predicting leakage is difficult if not impossible ahead of time, and that creating a continuous liability to account for leakage creates an incentive for project proponents to continually work to minimize it. What the approach may lack, however, is certainty for those tasked with implementing the activities, perhaps reducing the incentive to undertake the activity in the first place.

**Conclusion**

The literature review and subsequent analysis undertaken herein demonstrates that leakage poses a potential risk to the GHG benefits yielded by land-based mitigation activities. To guide
the development of processes and standards for land-based activities in Merced County, California, the analysis first characterizes those types of activities potentially facing the largest risk of leakage. Next, a simplified decision tree is developed to help guide users and decision-makers as to the situations under which the greatest risk of leakage may arise. Estimates of leakage rates are derived from the literature to further inform the process of evaluating the magnitude of leakage risk. The analysis concludes with a brief overview of mechanisms that may help to minimize leakage. Though it is hoped that the review and analysis will help stakeholders better evaluate leakage risk from land-based mitigation activities in Merced County, it is important to reinforce that the actual accounting and management of leakage requires attention to site-specific aspects of the activity, including market and carbon characteristics of the land affected and the specific set of planning or policy tools available to minimize or mitigate leakage risk. Such site- and project-specific analysis is beyond the scope of the current report.

Methods

This analysis is grounded in information derived from the peer-reviewed literature, so-called gray literature reports and discussion papers, and existing project-based accounting standards. Analysis began in January 2018 with a review of the extant literature on leakage. Owing to the ubiquitous nature of the term, analysis began with a review of known authoritative works on the subject, particularly those by Alig, McCarl, Murray, Sohngen, and Wear. The analysis then assessed papers cited by these initial authoritative works for their relevance to land-based activity leakage risk and/or accounting. Likewise reviewed for relevance to land-based activity leakage risk and/or accounting were papers citing these initial works, as listed on the Google Scholar record for each authoritative paper. The references in papers deemed relevant through this process were further reviewed for additional relevant sources. The analysis continued in this fashion until saturation, the point at which no new papers were identified for analysis.

A supplemental literature search was performed to assess the availability of adequate default leakage factors for either land-based activities generally or specific activities considered for use in Merced County. A Google Scholar search was conducted using the following terms: leakage “[activity]” “percent” “United States”, where activity is the particular activity considered for deployment in Merced. Searches using these terms retrieved few additional studies (5) deemed to be relevant to this analysis beyond those returned through the general literature review above.

Though this literature screen returned a large number of potentially-relevant papers, the following review is limited to those papers deemed to be most relevant by the author owing to the limited time available for the analysis. The analysis should be therefore considered indicative of scholarship on the matter, but not an exhaustive or systematic review of the extant literature.

References


